SUPPLEMENT

TO BRITISH TELECOMMUNICATIONS ENGINEERING

(formerly the Supplement to The Post Office Electrical Engineers' Journal)

Vol. 2 Part 2 July 1983

ISSN 0262-4028

TEC & SCOTEC GUIDANCE FOR STUDENTS

Contents

TEC: TELECOMMUNICATIONS SYSTEMS I 17
TEC: MICRO-ELECTRONICS I 21
TEC: ELECTRICAL AND ELECTRONIC PRINCIPLES II .. 24
TEC: MATHEMATICS II 30
TEC: ELECTRONICS III 35
TEC: LINES III 39
SCOTEC: ELECTRICAL PRINCIPLES III 43
SCOTEC: SWITCHING SYSTEMS III 46

TECHNICIAN EDUCATION COUNCIL

Certificate Programme in Telecommunications

Sets of model questions and answers for Technician Education Council (TEC) units are given below. The questions illustrate the types of questions that students may encounter, and are useful as practice material for the skills learned during the course.

Where additional text is given for educational purposes, it is shown within square brackets to distinguish it from information expected of students under examination conditions. Where possible, representative time limits or marks are shown for each question, and care has been taken to give model answers that reflect these limits.

We would like to emphasise that the questions are not representative of questions set by any particular college.

TEC: TELECOMMUNICATIONS SYSTEMS I

TEC unit number U81/748. Students are advised to read the notes above

Q1 Which of the following media constitute telecommunications systems?

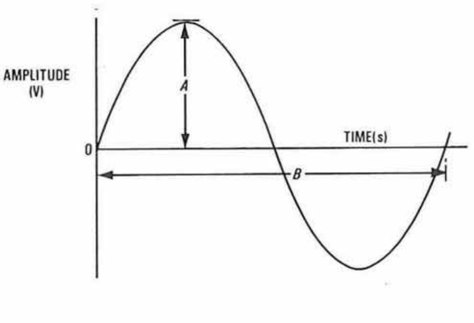
- (*a*) *Radio broadcasting.*
- (*b*) *Newspapers.*
- (*c*) *Telephones.*
- (*d*) *Telex.*
- (*e*) *Letters.*
- (*f*) *Television.*
- (*g*) *Semaphore signalling.* (*1 min*)

A1 (*a*), (*c*), (*d*), and (*f*).

[*Tutorial note:* Any telecommunications system involves the use of electrical signals for the transmission of information.]

Q2 For the radio wave shown in the sketch, express the following in terms of A and B:

- (*a*) *frequency,*
- (*b*) *amplitude,*
- (*c*) *wavelength, and*
- (*d*) *period.* (*3 min*)



A2 (*a*) $1/B$ hertz.

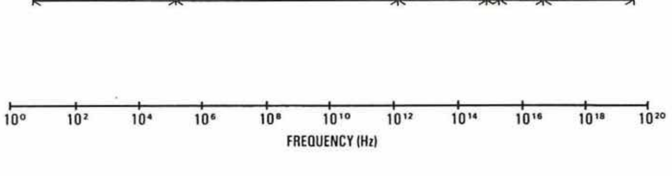
(*b*) A volts.

(*c*) $3 \times 10^8 \times B$ metres.

(*d*) B seconds.

Q3 For the electromagnetic spectrum shown in the sketch, match the regions lettered with the following sections of the spectrum.

- (*a*) *Visible light.*
- (*b*) *X-rays.*
- (*c*) *Audio.*
- (*d*) *Ultraviolet.*
- (*e*) *Radio.*
- (*f*) *Infra-red.* (*1 min*)



A3 (*a*) D

(*b*) F

(*c*) A

(*d*) E

(*e*) B

(*f*) C

Q4 What is meant by the term 'transducer'? Give 2 examples. (*3 min*)

A4 A transducer is a device that converts energy from one form into another. Examples include:

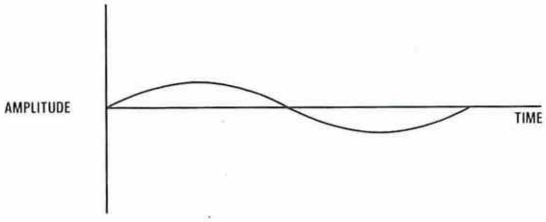
(*a*) microphones (sound to electrical),

(*b*) television cameras (light to electrical),

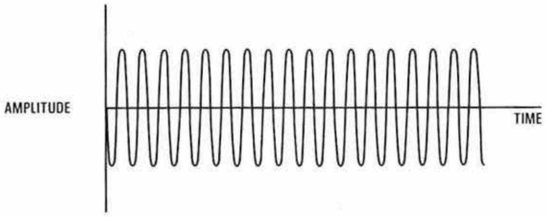
(*c*) motors (electrical to mechanical), and

(*d*) loudspeakers (electrical to sound).

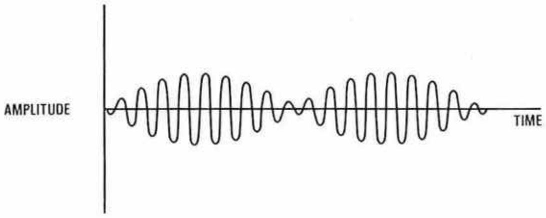
Q5 *In terms of an amplitude-modulated radio system, identify the 3 waveforms shown below.* (*2 min*)



(*a*)



(*b*)



(*c*)

A5 (*a*) is the signal,

(*b*) is the carrier wave, and

(*c*) is the carrier amplitude modulated by the signal.

Q6 *A radio frequency of 1260 kHz is used as the carrier in an amplitude-modulated system for a signal in the range of 20 Hz to 20 kHz. What are the limits of the sideband frequencies?* (*2 min*)

A6 1240 kHz to 1259·98 kHz and 1260·02 kHz to 1280 kHz.

Q7 *A telephone system for 5 users is required. This could be set up either by*

(*a*) *giving each user a direct connection to every other user, or*

(*b*) *using a local exchange.*

Find the number of pairs of conductors required for each system. Comment on your answer. (*3 min*)

A7 (*a*) requires 10 lines, and

(*b*) requires 5 lines.

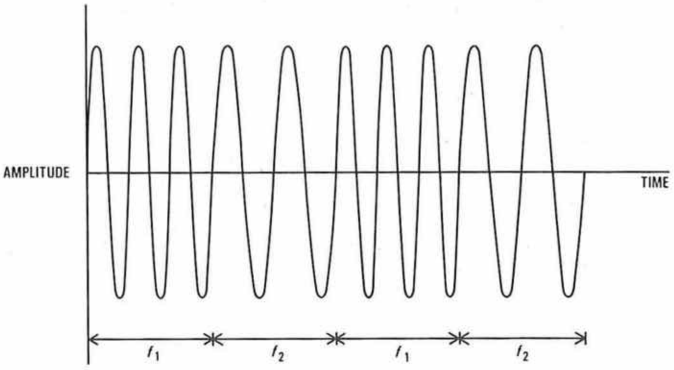
System (*b*) would probably be more sensible in practice unless the 5 users are physically very close together, in which case the cost of exchange equipment might not be offset by the saving in cable. For larger numbers of users, an exchange system would become more advantageous.

Q8 *Give 2 advantages of Telex over telephone services for the business user.* (*3 min*)

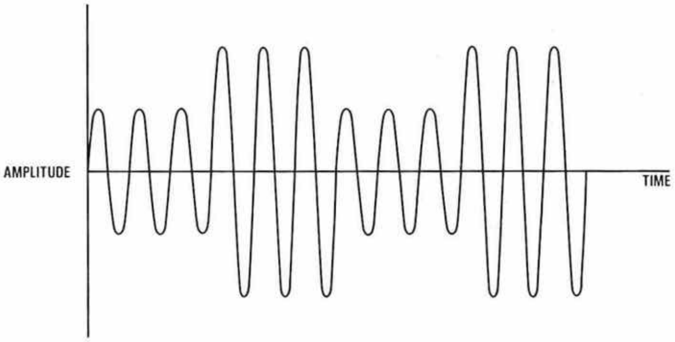
A8 (*a*) Telex provides a permanent written record of a message.

(*b*) It is not necessary for the recipient to be present to receive a Telex message; this is useful for international communications across time zones.

Q9 *Identify the shape of the signal wave and the modulation system used in the 2 waves shown below.* (*2 min*)



(*a*)



(*b*)

A9 In both cases the signal is a square wave;

(*a*) shows frequency modulation, and

(*b*) shows amplitude modulation.

Q10 *When using the telephone, you may hear the following signals. What are their meanings?*

(*a*) *continuous 400 Hz tone*

(*b*) *continuous 50 Hz tone*

(*c*) *intermittent 400 Hz tone*

(*d*) *repeated double-pulsed 400 Hz tone* (*3 min*)

A10 (*a*) The number you have dialled is unobtainable.

(*b*) The exchange is ready for you to dial.

(*c*) The number you have dialled is engaged.

(*d*) The number you have dialled is ringing.

Q11 *Give typical facilities available from the following first-group-selector levels:*

(*a*) *0,*

(*b*) *9,*

(*c*) *8,*

(*d*) *2–7, and*

(*e*) *1.* (*4 min*)

A11 (*a*) Subscriber trunk dialling facilities.

(*b*) To other exchanges and emergency services.

(*c*) To other local exchanges.

(*d*) To second group selectors.

(*e*) To operator and other special services.

Q12 In a switching matrix where 200 input lines have access to 200 output lines, how many crosspoints are needed? (*1 min*)

A12 40 000

Q13 What is a digital signal? (*3 min*)

A13 A digital signal is one which changes very quickly between various fixed levels, as opposed to an analogue signal which changes continuously.

Q14 What is a modem? (*3 min*)

A14 A modem is a device that interfaces computers or data terminals to telecommunications equipment. It is a 2-way device. In one direction it converts outgoing digital signals to analogue signals that can be transmitted over the telecommunications network. In the other direction, it converts incoming analogue signals into digital form to operate the data terminal or computer. The term *modem* is a contraction of *mo*dulator/*dem*odulator.

Q15 From the following list of devices, make a list of those that can be used for

(*a*) *data input, and*

(*b*) *data output.*

List of devices:

(*i*) *visual display unit,*
(*ii*) *punched-card reader,*
(*iii*) *magnetic disc,*
(*iv*) *teleprinter, and*
(*v*) *paper-tape punch.* (*3 min*)

A15 (*a*) (*i*), (*ii*), (*iii*), and (*iv*).
(*b*) (*i*), (*iii*), (*iv*), and (*v*).

Q16 Define the following terms:

(*a*) *software,*
(*b*) *on-line, and*
(*c*) *byte.* (*6 min*)

A16 (*a*) Software consists of programs, languages and other forms of instructions used for the control of a computer and for the interpretation of output.

(*b*) A device (for example, a printer) which is ON-LINE is under the direct control of the central computer, ready to accept data or instructions from it.

(*c*) A byte is a group of (usually 8) binary digits (or bits) treated as a single unit.

Q17 State whether the following statements are true or false.

(*a*) *A radio wave cannot pass through a vacuum.*
(*b*) *Very-high frequency radio is propagated as space waves.*
(*c*) *Insulators normally reflect radio waves.* (*2 min*)

A17 (*a*) False.
(*b*) True.
(*c*) False.

Q18 Match the following list of broadcast frequencies with the list of ranges where good reception might be expected.

List of frequencies:
(*a*) *150 kHz*
(*b*) *1800 kHz*
(*c*) *80 MHz*
(*d*) *20 MHz*

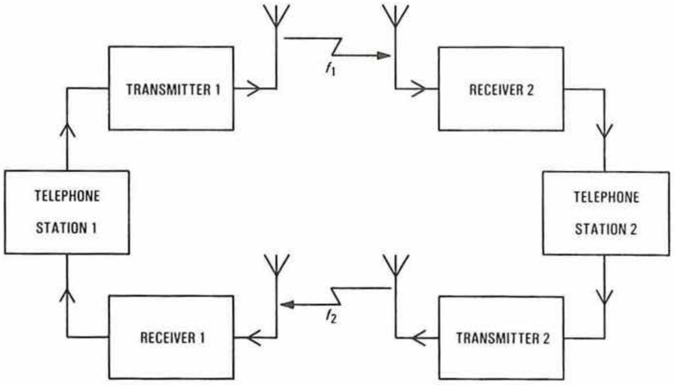
List of ranges:
(*i*) *10 km*
(*ii*) *10 000 km*
(*iii*) *2000 km*
(*iv*) *200 km*

(*2 min*)

A18 (*a*) (*iii*)
(*b*) (*iv*)
(*c*) (*i*)
(*d*) (*ii*)

Q19 Draw a block diagram of a 2-way radio-telephony system. (*5 min*)

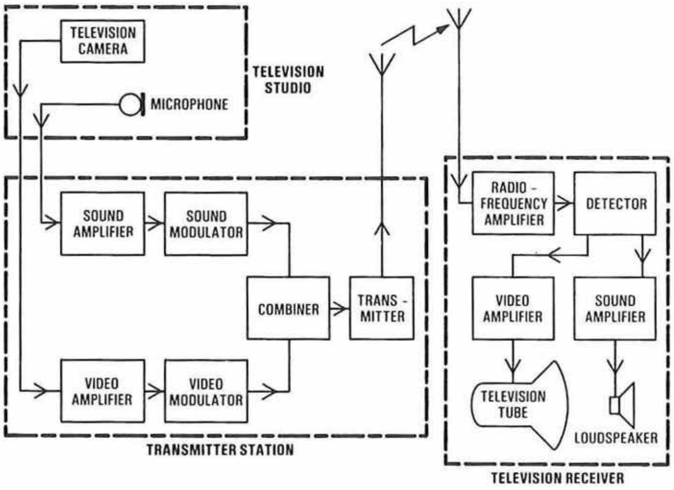
A19



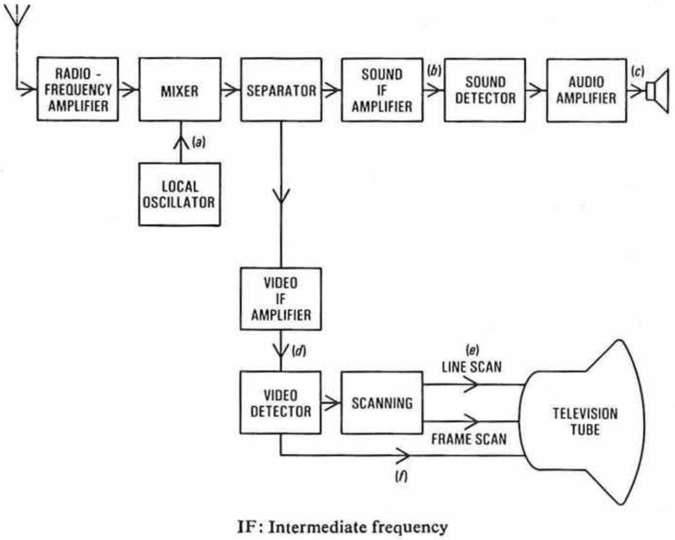
Note: f_1 and f_2 refer to the 2 different frequencies of the radio-frequency carriers.

Q20 Draw a block diagram of a television broadcast system. (*10 min*)

A20

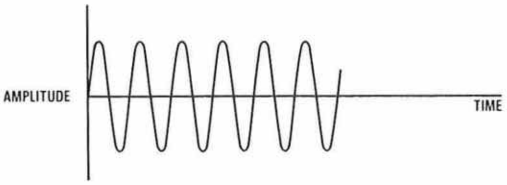


Q21 From the block diagram of an ultra-high frequency television receiver, shown below, sketch the waveform expected at points labelled (*a*)–(*f*). (*15 min*)

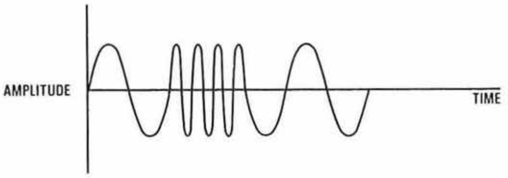


IF: Intermediate frequency

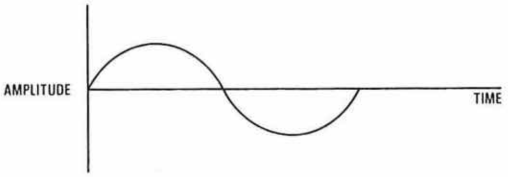
A21



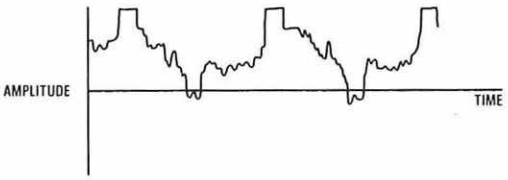
(*a*) IF carrier



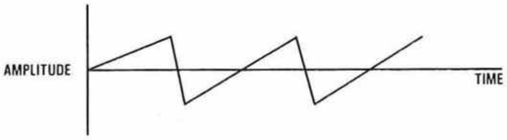
(*b*) Frequency-modulated IF



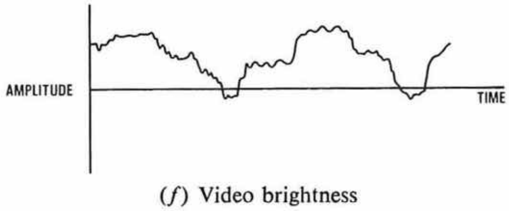
(*c*) Audio



(*d*) Video signal and line-synchronising pulses



(*e*) Scanning



(*f*) Video brightness

Q22 How is the impression of a moving picture conveyed by a television set? (*6 min*)

A22 The human eye has a certain *persistence of vision*, which means that any image registered by the eye is retained by the brain for about 0·05 s. Therefore, if a series of still pictures, all slightly different, are presented at intervals of less than 0·05 s, the brain superimposes them to give the impression of continuous movement.

Q23 How many lines are used in the British ultra-high-frequency television system, and what frequency range is used? (*2 min*)

A23 625 lines; 300–3000 MHz.

Q24 What is meant by the term 'aspect ratio' in television? What value of aspect ratio is used in British television? (*2 min*)

A24 The aspect ratio is the ratio of the height to the width of a television screen. The British standard is 4:3.

Q25 What is meant by 'interlacing'? (*7 min*)

A25 If all the lines of a television picture were scanned in sequence from top to bottom, the time interval between the start and end of the scan could give some flicker to the picture. To improve the picture quality (without simply scanning more often, which would improve the picture but also increase the bandwidth requirement for transmission), the picture is scanned in 2 stages; firstly, the odd-numbered lines and then the even-numbered lines. The overall visual effect is a more stable picture. The combination of the 2 part scans of alternate lines is known as *interlacing*.

Q26 What is the principal difference in the operation of colour television receivers compared with monochrome? (*10 min*)

A26 In a monochrome television, the picture is produced by a single electron beam of variable intensity scanning the screen, the light output from the screen coating being proportional to beam intensity. In one type of colour receiver, there are 3 separate electron beams representing the 3 primary colours red, green and blue. The screen coating is made up of areas which glow red, green and blue when struck by electrons. A mask behind the screen prevents electrons from the 'red' gun hitting any part of the screen other than those which glow red; similarly for green and blue. Any colour can be made up from a combination of red, green and blue, ranging from black (no red, green or blue) to white (red, green and blue).

Q27 What is 'teletext'? (*10 min*)

A27 Teletext is a service broadcast simultaneously with normal television programmes. A small extra component is added to the normal signal which, with a suitably equipped television set, can be decoded into a text display on the television screen in place of the normal picture. (A set not equipped for teletext merely ignores the extra signal component). Pages of information on different subjects are available and these can be selected by using a keypad. Teletext can also provide subtitles to programmes, or news flashes, superimposed on the normal picture. Ceefax is the teletext service operated by the British Broadcasting Corporation and Oracle is the Independent Broadcasting Authority's service.

Q28 What is Prestel? (*10 min*)

A28 Prestel is an interactive information service operated by British Telecom. Customers can access pages of information stored on files in a central computer by using a modified television receiver or specially-designed terminal linked to the computer by a telephone line. The information is provided by a large number of firms and other agencies and is continually updated by them. As well as simply reading pages of information displayed on the screen, users can send messages; for example, to order air tickets or to send a message to another user.

Q29 Describe briefly how a Prestel user accesses the central computer and locates particular information. (*10 min*)

A29 The electronic circuitry associated with a Prestel receiver (either integral with or as an adaptor to an ordinary television set) includes a connection to a jack socket on a telephone line, and a keypad. Once the equipment is plugged in, the computer is dialled by pressing a single key, and the user is automatically registered. The required information can be found either by progressing through a series of index pages selected by numerical codes on the keypad or, if the relevant page number is already known (or found in a printed directory), by accessing the page directly.

Q30 Describe the principles of a pulsed primary radar system. (*10 min*)

A30 When radio waves strike a reflecting surface, some of the energy of the waves returns to the source. In a pulsed primary radar system a signal consisting of a series of short pulses is transmitted. In the intervals between pulses, the reflection of the last pulse can be received at the transmitter. If the time taken for the pulse to travel to the reflecting surface and back is measured, the distance of the reflecting surface from the transmitter can be calculated from the formula:

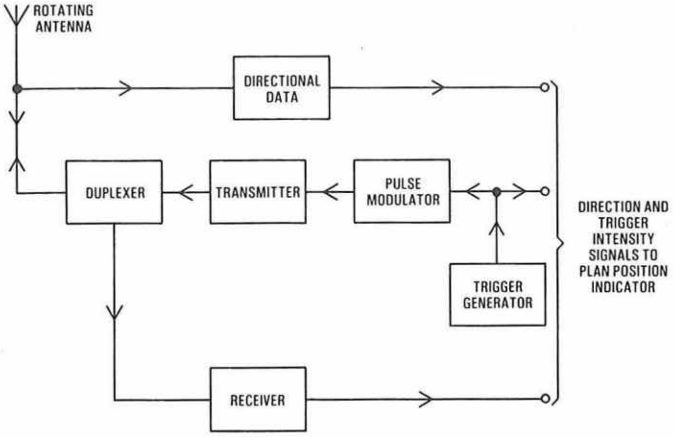
distance = $\frac{1}{2}$ × speed of the signal (3×10^8 m/s for electromagnetic
waves in free space)
× time interval.

Q31 What is the advantage of a plan position indicator display over an A-scope display? (*3 min*)

A31 An A-scope system enables measurement of range (on the principles outlined in A30) but a plan position indicator display also gives information on direction.

Q32 Draw a block diagram of a pulsed primary radar system suitable for driving a plan position indicator display. (*10 min*)

A32



Q33 Describe how a plan position indicator display operates. (*10 min*)

A33 A plan position indicator display consists of a circular cathode-ray tube, with the beam at a *home* position at the centre of the screen. The screen is calibrated in concentric circles representing distance and radial lines representing bearing. The observer's position is represented by the centre of the screen. The intensity of the beam is controlled by the intensity of the reflected signal. The beam scans from the centre to the circumference of the screen for every pulse, at the same bearing as the antenna is currently facing. The beam starts moving when the pulse is transmitted, at low intensity corresponding to no received reflection. When a reflection is received, the beam, which will have travelled a distance from the centre of the screen proportional to the distance between the reflector and observer, becomes bright, thereby creating an image of the reflector on the screen.

Q34 What is secondary radar? (*6 min*)

A34 In primary radar, the strength of the echo signal depends on the nature of the reflector. Secondary radars provide high-magnitude signals from known geographical locations. On receipt of a signal from a primary radar, the secondary radar transmits a pulse on a different frequency. Coded pulses can be used for identification. Secondary radar also has the advantage that the received signal is stronger.

Q35 What is the basic principle of the Decca maritime navigation system? (*7 min*)

A35 Several radio transmitters, situated in different positions around the area to be covered, operate locked in phase. A ship at any position can, by receiving from any 2 transmitters, determine the phase relationship between the 2 waves at that point. Since phase at any point relates to distance and wavelength, the exact position of the ship can be found by using a suitably prepared chart showing the phase relationships of the waves from the various transmitters over the whole area.

Q36 Match items from the list of frequencies with the appropriate radio navigation systems.

Frequencies:	*Navigation systems:*
(*a*) *10 kHz*	(*i*) *Loran*
(*b*) *400 MHz*	(*ii*) *Consol*
(*c*) *130 kHz continuous*	(*iii*) *Decca*
(*d*) *100 kHz pulsed*	(*iv*) *Omega*
(*e*) *300 kHz*	(*v*) *Satellite*

(*3 min*)

A36 (*a*) (*iv*); (*b*) (*v*); (*c*) (*iii*); (*d*) (*i*) and (*e*) (*ii*).

Questions and answers contributed by P. Byass

TEC: MICRO-ELECTRONICS SYSTEMS I

TEC unit number U79/602. Students are advised to read the notes on p. 17

Q1 Which of the following statements are true of any system?

(*a*) *Its output depends only upon its inputs.*
(*b*) *An internal program produces its outputs.*
(*c*) *The inputs are processed to produce its outputs.*
(*d*) *Its outputs are determined solely by its internal state.* (*1 min*)

A1 (*c*) The inputs are processed to produce its outputs.

Q2 What is the function of a transducer? (*3 min*)

A2 A transducer is a device that receives an input signal as one form of energy and converts it into another form. In a micro-electronic system the function of a transducer is generally to convert physical variables such as temperature, pressure and speed into electrical signals.

Q3 What are the inputs, outputs, and the process of the following systems:

(*a*) *a radio receiver, and*
(*b*) *an immersion heater.* (*8 min*)

A3 (*a*) **Radio Receiver.**

Inputs The radio-frequency signal from the aerial is the main input, but there must also be an input of energy from a power supply and operator inputs to set the controls.

Outputs The output is in the form of sound from the loudspeaker.

Process The radio receiver converts low-amplitude radio-frequency signals into sound vibrations.

(*b*) **Immersion Heater.**

Inputs The input is electric power.

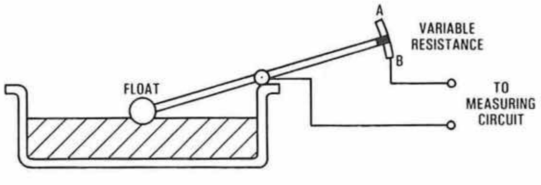
Outputs The output is heat energy.

Process The immersion heater converts electrical energy into heat and thereby increases the temperature of the surrounding liquid.

Q4 Describe how the level of liquid in a tank could be converted into an electrical signal. (*6 min*)

A4 The simplest type of liquid-level transducer uses a float connected to a variable resistance as shown in the sketch.

The system is arranged so that when the tank is empty the float rests on the bottom of the tank and the slider of the variable resistance is at point A. This places a high resistance in the measuring circuit. As the liquid level in the tank rises, the slider moves towards point B and reduces the circuit resistance. The resistance in the measuring circuit is therefore proportional to the liquid level in the tank.



Q5 How can a value of temperature be converted into an electrical signal? (*6 min*)

A5 Most temperature transducers are based on devices that change their resistance with temperature, such as thermistors or platinum-resistance thermometers.

A thermistor is a semiconductor device which generally exhibits a high resistance at low temperatures and a low resistance at high temperatures. Unfortunately, over the range 0–100°C thermistors are very non-linear, and this makes it difficult to obtain accurate readings.

In comparison, a platinum-resistance thermometer is highly linear. It consists of a length of pure platinum wire with a known resistance at 0°C. When it is subjected to a change of temperature, its resistance changes by a known amount.

Both a thermistor and platinum-resistance thermometer can be included as the active element in a resistance-measuring circuit, the output of which would be an electrical signal.

Q6 Which of the following is necessary for electrical systems:

(*a*) *a temperature input,*

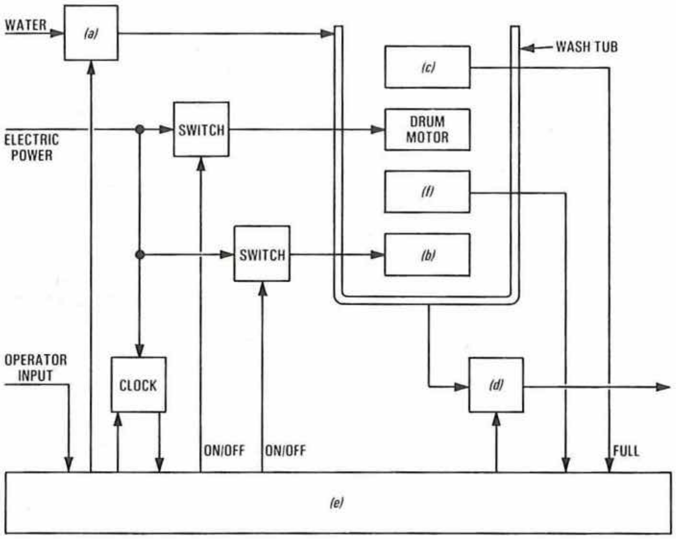
(*b*) *a power supply,*

(*c*) *a microprocessor, or*

(*d*) *a level detector.* (*1 min*)

A6 (*b*) a power supply.

Q7 Identify the function of each of the blocks marked with a letter on the block diagram of a washing machine shown below. (*10 min*)



A7 (*a*) Water inlet valve. This controls the flow of water into the wash tub.

(*b*) Heater. This heats the water to the required wash temperature.

(*c*) Level detector. This indicates when the water has reached the required depth.

(*d*) Outlet valve and pump. This drains the water from the wash tub.

(*e*) Controller. This reads the required wash sequence selected by the operator and then controls the other parts of the machine in a way determined by its built-in program.

(*f*) Temperature transducer. This indicates when the water has reached the required temperature.

Q8 Describe the input, output and process of the following parts of a washing machine:

(*a*) *the drum motor, and*

(*b*) *the clock.* (*10 min*)

A8 (*a*) **Drum Motor.**

Input The input to the drum motor is electric power, which is switched on or off by the controller.

Output The output is the rotary motion of its shaft, which is connected to the wash drum.

Process Input electric energy is converted into mechanical rotation of the shaft, which then turns the wash drum at the required speed. Different drum speeds can be obtained by electronic control of the motor power supply.

(*b*) **Clock.**

Input The main input is electric power, but in addition a *stop/start* signal can be provided by the controller.

Output The output can be a rotary movement in the case of a mechanical clock, or an electronic signal for a crystal clock, each one being a measure of the time that has elapsed from the beginning of any operation.

Process The clock uses electric power to provide a measure of elapsed time in either mechanical or electronic form. It is used to time each part of the washing-machine cycle.

Q9 What determines the sequence of operations carried out by a washing machine. (*3 min*)

A9 The sequence of operations carried out by a washing machine is built into the controller during manufacture. In a mechanically-controlled machine the operations are determined by the positions of the contacts in the rotating-switch assembly. In an electronic machine the operations are controlled by the system firmware. User controls simply allow the operator to select one of the built-in set of wash sequences.

Q10 Choose one of the following answers to complete the sentence:
'The set of stored instructions within a washing machine can be identified as..................'

List of options:

(*a*) *a program.*

(*b*) *the controller.*

(*c*) *firmware.*

(*d*) *part of a flow chart.* (*1 min*)

A10 (*a*) a program.

Q11 The operation of a washing machine can be described as a sequence of events. Copy the list below and complete it for one such sequence, which starts as soon as power is applied.

Step Number	*Operation*
1	*Read control settings*
2	*Fill with cold water*

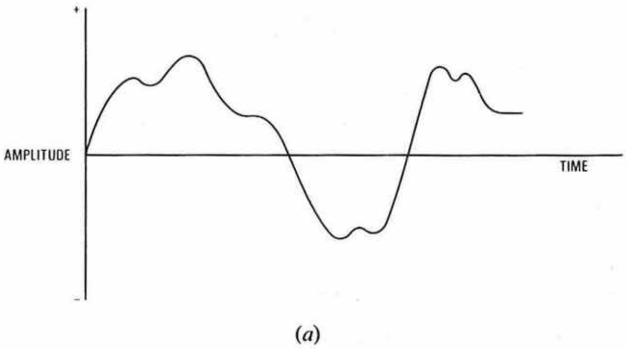
(*5 min*)

A11

Step Number	Operation
1	Read control settings
2	Fill with cold water
3	Heat water to required temperature
4	Wash for fixed time
5	Empty water
6	Fill with cold water
7	Rinse for fixed time
8	Empty water
9	Spin for fixed time
10	Stop

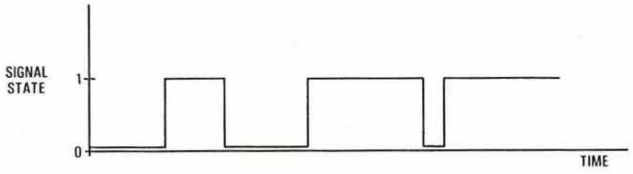
Q12 With the aid of a waveform diagram, explain the difference between an analogue and a digital signal. (*6 min*)

A12 An analogue signal can vary continuously and take on any value between predetermined limits. It changes very little from one instant to the next, as shown in sketch (*a*).



(*a*)

A digital signal can be equal to only one of a number of predetermined discrete values. For example, a digital signal in a binary system may take only one of two values, generally known as LOGIC *1* and LOGIC *0*. Because the signal changes very rapidly between the allowed values, it is said to be discontinuous. A typical signal is shown in sketch (*b*).



(*b*)

Q13 *For the systems listed below, state whether each is mainly either analogue or digital.*

(*a*) *A pocket calculator,*

(*b*) *a moving-coil voltmeter,*

(*c*) *a bench power supply,*

(*d*) *an electric motor, and*

(*e*) *a home computer.* (*3 min*)

A13 (*a*) A pocket calculator is a digital system.

(*b*) A moving coil voltmeter is an analogue system.

(*c*) A bench power supply is an analogue system.

(*d*) An electric motor is an analogue system.

(*e*) A home computer is a digital system.

Q14 *Complete the following sentence:*

'A bit is..................' (*1 min*)

A14 A bit is a single binary digit; it can take on the value of either a 0 or a 1.

Q15 *Groups of bits can be used to represent 3 types of information within a micro-electronic system. What types are they?* (*2 min*)

A15 Groups of bits can represent

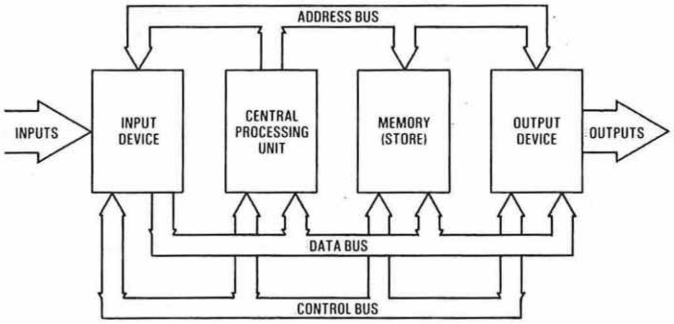
(*a*) numbers,

(*b*) alphanumeric characters, and

(*c*) machine instructions.

Q16 *Draw a block diagram showing a simple microprocessor system containing a central processing unit, a memory (store), an input device and an output device, together with the interconnecting busses. Label each part clearly.* (*6 min*)

A16



Q17 *Which of the following answers completes the sentence:*

'A large-scale integrated circuit contains..................'

List of options:

(*a*) *between 10 and 100 devices per chip.*

(*b*) *tens of thousands of devices per chip.*

(*c*) *up to 10 devices per chip.*

(*d*) *between 100 and 1000 devices per chip.* (*1 min*)

A17 (*d*) between 100 and 1000 devices per chip.

Q18 *Briefly explain the operation of the following devices:*

(*a*) *a visual display unit, and*

(*b*) *a teletype.* (*8 min*)

A18 (*a*) A visual display unit (VDU) is a computer peripheral which contains a television-like screen and a keyboard. The television screen is used to display output data from the computer in the form of written text or pictures. Generally, the textual information is displayed as a series of rows of characters; most commercial VDUs support 24 rows of 80 characters each.

The keyboard is used to input data to the computer and is not connected directly to the screen. However, the computer may echo all the keys pressed, and so display them for the benefit of the operator.

Data is generally passed between the VDU and computer over a serial data link at relatively high speed (up to about 2000 characters/s). Since the display has to be refreshed 50 times per second, all VDUs contain a semiconductor memory to store one screen-full of information.

(*b*) A teletype is a computer peripheral which contains both a keyboard and a printer. The keyboard is used to send character codes to a computer, which may then echo the same characters to the printer and so produce a copy on paper known as a *hard copy*. Computers may send other characters, such as the listing of a program, directly to the printer. Teletypes are limited in speed because of the mechanical printing operation, and typically operate at between 10 and 60 characters/s.

Some teletypes also include a paper-tape reading and punching facility.

Q19 *Compare the use of cassette tapes and floppy discs for storing computer programs or data.* (*8 min*)

A19 Cassette tape and floppy disc are both widely used to store computer programs, but differ considerably in their capacity, access time, data transfer rate and cost.

The capacity of a C60 cassette tape is typically 400 Kbytes, and that of a C15 data cassette about 100 Kbytes. This compares favourably with a floppy disc, which has a typical capacity of about 200 Kbytes for the 133 mm (5·25 in) size, and 1 Mbyte for the 203 mm (8 in) size.

However, access times are considerably different. For a C60 cassette, playing for 30 min each side, the average access time is 15 min. Similarly, for a C15 cassette, the access time is 3·75 min. Both sizes of floppy disc have an access time of about 0·5 s.

Data is transferred from cassette relatively slowly, at between 15 and 120 characters/s. However, data is transferred from a floppy disc unit at about 15000 characters/s.

Floppy-disc drives are much more expensive than cassette-tape players. Both cassette tape and floppy discs are low-cost storage media, cassette tapes being generally cheaper.

Q20 *What is the function of a peripheral in a computer system?* (*3 min*)

A20 Peripherals are devices that enable a computer to input and output information. Without them, computers would not be able to communicate with the outside world. Typical peripherals include keyboards, visual display units, printers and floppy-disc units. Each contains transducers which convert the input and output signals between the computer logic levels and other forms.

Q21 *What is meant by the following terms:*

(*a*) *hardware,*

(*b*) *ROM,*

(*c*) *firmware, and*

(*d*) *software.* (*6 min*)

A21 (*a*) Hardware is the physical components of a system, such as the integrated circuits, the chassis and the printed-wiring boards.

(*b*) ROM is an abbreviation for *read-only memory*. It is a semiconductor memory device which cannot be written into, and, therefore, its contents cannot be changed during the execution of a program. It maintains the data stored in it even when the power supply is switched off.

(*c*) Firmware refers to the programs or data stored in a ROM. They are not lost when the power is switched off.

(*d*) Software refers to the programs held in random-access memory. They can readily be changed or corrupted and are lost when the power is removed.

Q22 *Briefly explain why a program is required in a microprocessor-based system.* (*2 min*)

A22 A microprocessor operates only when it is given a series of instructions to execute, which are known as the *program*. In the absence of a program, a microprocessor can do nothing.

Q23 *(a) Write a program using the instruction set given in the table, under the headings of Address, Mnemonic and Hexadecimal Code, to perform the following function:*

Add the number 08 hex to the contents of memory address 2030 hex, and store the result in address 2031 hex. Then decrement the accumulator, and store the result in address 2032 hex.

Start the program at address 2000 hex and assume that address 2030 hex is already loaded with the data 98 hex.

Shortened Z80 Instruction Set

Mnemonic	*Hexadecimal Code*	*Comment*
LD A,n	*3E n*	*Load register A with n*
LD A,(nn)	*3A n n*	*Load register A with the contents of memory location nn*
LD (nn),A	*32 n n*	*Load memory location nn with the contents of register A*
ADD A,n	*C6 n*	*Add n to the contents of register A*
INC A	*3C*	*Add 1 to the contents of register A*
DEC A	*3D*	*Subtract 1 from the contents of register A*
JP nn	*C3 n n*	*Continue execution from memory location nn*
JP NZ nn	*C2 n n*	*Continue execution from memory location nn if the zero flag is set*
HALT	*76*	*Stop program*

Notes:
(i) n is a single-byte (2-digit) hexadecimal constant.
(ii) For instruction codes that include an address of a memory location, the first byte following the instruction code refers to the least significant byte of the address and the second byte to the most significant byte of the address.

(*b*) *What are the contents of addresses 2031 hex and 2032 hex after the program in part* (*a*) *has been executed?* (*15 min*)

A23 (*a*)

Address	Mnemonic	Hexadecimal Code
2000	LD A,(2030 hex)	3A 30 20
2003	ADD A,08	C6 08
2005	LD (2031 hex), A	32 31 20
2008	DEC A	3D
2009	LD (2032 hex),A	32 32 20
200C	HALT	76

(*b*) Address 2031 hex will contain A0 hex.
Address 2032 hex will contain 9F hex.

[*Tutorial note:* The instruction set given above could be replaced with a similar group of instructions or simply other mnemonics for other types of microprocessor.]

Q24 *What will be the effect of executing the following program? (Refer to the instruction set given in Q23.)*

Address	*Mnemonic*	*Hexadecimal Code*
1800	*LD A,(180D hex)*	*3A 0D 18*
1803	*DEC A*	*3D*
1804	*JP NZ 1803 hex*	*C2 03 18*
1807	*LD A,80 hex*	*3E 80*
1809	*LD (180D hex),A*	*32 0D 18*
180C	*HALT*	*76*
180D	*Data*	*FF*

(*10 min*)

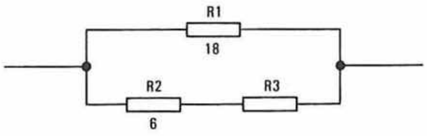
A24 The accumulator is first loaded with the data FF from address 180D hex. It is then decremented to FE and tested for a non-zero result. Since the result is not initially zero, the program jumps back to address 1803 hex, and the accumulator is decremented again. This happens a total of 255 times until the accumulator value reaches zero. This part of the program constitutes a short delay. After the delay, the accumulator is loaded with 80 hex and this value is put into address 180D hex. The program then halts.

Questions and answers contributed by D. Turner

TEC: ELECTRICAL AND ELECTRONIC PRINCIPLES II

TEC unit number U81/747. Students are advised to read the notes on p. 17

Q1 *For the circuit shown below, determine the value of resistor R3 given that the total resistance of the circuit is 10 Ω.* (*3 min*)



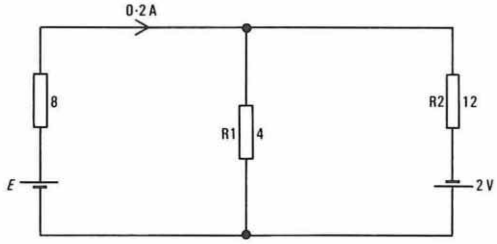
A1 Let

$$
\begin{aligned}
R_2 + R_3 &= R_x. \\
\therefore \quad 10 &= \frac{18 \times R_x}{18 + R_x}. \\
\therefore \quad 180 + 10R_x &= 18R_x, \\
\text{and} \quad 180 &= 18R_x - 10R_x, \\
&= 8R_x. \\
\therefore \quad R_x &= \frac{180}{8}, \\
&= 22{\cdot}5\ \Omega. \\
\text{But} \quad R_x &= R_2 + R_3. \\
\therefore \quad R_3 &= 22{\cdot}5 - 6, \\
&= \underline{16{\cdot}5\ \Omega.}
\end{aligned}
$$

Q2 *State Kirchhoff's current law.* (*1 min*)

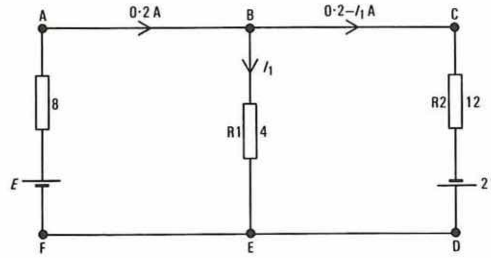
A2 The total current flowing towards a junction in a circuit is equal to the total current flowing away from that junction.

Q3 *For the circuit shown below, determine the current in resistors R1 and R2 and the value of E.* (*8 min*)



A3 Assuming the directions of the unknown currents are as shown in the sketch, then for loop ABEFA

$$
\begin{aligned}
E &= (8 \times 0{\cdot}2) + 4I_1, \\
&= 1{\cdot}6 + 4I_1. \qquad \ldots\ldots \ (1)
\end{aligned}
$$



Similarly, for loop BCDEB

$$\begin{aligned} 2 &= 12(0{\cdot}2 - I_1) - 4I_1, \\ &= 2{\cdot}4 - 16I_1. \\ \therefore\quad 0{\cdot}4 &= 16I_1. \\ \therefore\quad I_1 &= 0{\cdot}025\text{ A}. \end{aligned}$$

The current through R1 is in the direction shown. Therefore, the current through R2

$$\begin{aligned} &= 0{\cdot}2 - 0{\cdot}025, \\ &= \underline{0{\cdot}175\text{ A, in the direction shown.}} \end{aligned}$$

[*Tutorial note:* Negative values of current indicate that the direction shown is opposite to the actual direction.]

Substituting for I_1 in equation 1,

$$E = 1{\cdot}6 + 4 \times 0{\cdot}025 = \underline{1{\cdot}7\text{ V}}.$$

Q4 Explain the relationship between charged bodies. (*5 min*)

A4 All charged bodies can be regarded as being surrounded by an electric field which produces a force on other charged bodies in the field. The direction of the field indicates the direction in which a free positive charge would move within the field.

When 2 charges are placed in close proximity, each charge experiences a force due to the field of the other charge. If the charges are unlike charges (that is, one negative and the other positive), then the forces on the charges are such that the 2 charges are attracted towards each other. If the charges are like charges (both positive or both negative), then the 2 charges are repelled away from each other.

Q5 A capacitor charges at a constant rate of 2 mA over a period of 36 ms. If the applied voltage is 9 V, determine the capacitance. (*2 min*)

A5 The charge on the capacitor, Q, in coulombs

$$\begin{aligned} &= \text{rate of charge} \times \text{time}, \\ &= 2 \times 10^{-3} \times 36 \times 10^{-3}\text{ C}, \\ &= 72\ \mu\text{C}. \end{aligned}$$

The capacitance, C, is given by Q/V farads, where V (volts) is the voltage across the capacitor.

$$\therefore\quad C = \frac{72 \times 10^{-6}}{9}\text{ F} = \underline{8\ \mu\text{F}}.$$

Q6 Define dielectric constant. (*2 min*)

A6 The dielectric constant (also known as *relative permittivity*) of a dielectric is the ratio of absolute permittivity and the permittivity of free space; the resultant quantity is dimensionless.

[*Tutorial note:* Dielectric constant can also be defined as the multiplying factor of a dielectric material. This factor, when multiplied by the permittivity of free space, will give the absolute permittivity of the dielectric material.]

Q7 Three capacitors of capacitance 5 μF, 15 μF and 30 μF, respectively, are connected in series to a 200 V DC supply. Determine the total capacitance of the circuit and the charge on each capacitor. (*3 min*)

A7 The total capacitance of the circuit, C_t (microfarads), is given by

$$\begin{aligned} \frac{1}{C_t} &= \frac{1}{5} + \frac{1}{15} + \frac{1}{30}, \\ &= \frac{6 + 2 + 1}{30}, \\ &= \frac{9}{30}. \\ \therefore\quad C_t &= \frac{30}{9} = \underline{3{\cdot}33\ \mu\text{F}}. \end{aligned}$$

As the circuit is a series circuit, each capacitor has the same charge which is equal to the overall charge of the circuit.

The total charge, Q microcoulombs, is given by C_tV, where V (volts) is the voltage of the supply.

$$\therefore\quad Q = 3{\cdot}33 \times 200 = \underline{666\ \mu\text{C}}.$$

Q8 Define the magnetic term 'reluctance'. (*2 min*)

A8 Reluctance (symbol R) can be regarded as the difficulty in creating a magnetic flux in a magnetic or non-magnetic medium. It can be defined as the ratio of magnetomotive force to the total magnetic flux in the magnetic circuit; that is,

$$R = \frac{\text{magnetomotive force}}{\text{magnetic flux}}.$$

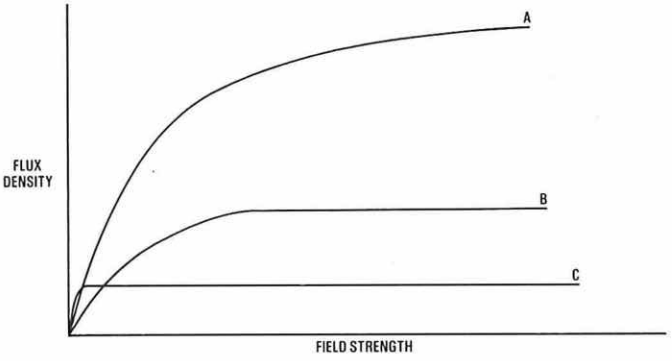
The unit of reluctance is henrys^{-1}.

Q9 State which of the following magnetisation curves refers to

(*a*) *cast iron,*

(*b*) *a ferrite, and*

(*c*) *stalloy.* (*1 min*)



A9 (*a*) B,

(*b*) C, and

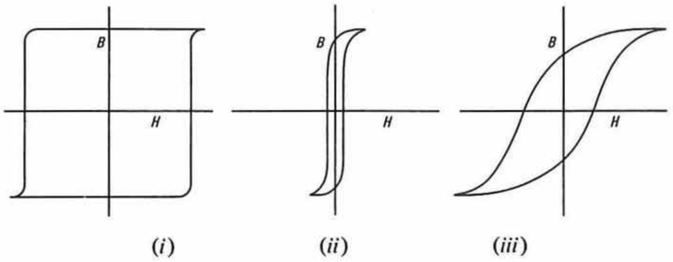
(*c*) A.

Q10 The 3 hysteresis loops shown below are all drawn to the same scale.

(*a*) *Which loop displays the greatest loss?*

(*b*) *Which loop displays the greatest remanence?*

(*c*) *Which loop is the most suitable characteristic for transformer cores?* (*1½ min*)



(*i*) (*ii*) (*iii*)

B: Flux density
H: Magnetic field strength

A10 (*a*) (*i*).

(*b*) (*i*).

(*c*) (*ii*).

Q11 A magnetic circuit has a magnetic field strength of 2000 A/m and a flux density of 500 mT. Determine the relative permeability of the material. (*3 min*)

A11 The relative permeability, μ_r, is given by

$$\mu_r\mu_o = \frac{B}{H},$$

where B is the flux density (teslas), H is the magnetic field strength (amperes/metre), and μ_o is the absolute permeability of free space ($4\pi \times 10^{-7}$ H/m).

$$\begin{aligned} \therefore\quad \mu_r &= \frac{B}{\mu_oH} = \frac{500 \times 10^{-3}}{2000 \times 4\pi \times 10^{-7}}, \\ &= \underline{198{\cdot}9}. \end{aligned}$$

Q12 *A steady flux of 300 μWb surrounding a coil of 2000 turns is reduced by 25% of this value in 1·5 ms. Determine the EMF induced across the terminals of the coil.* (*3 min*)

A12 The change in flux $= 300 - (300 \times 0{\cdot}75)$,

$$= 300 - 225,$$

$$= 75\ \mu\text{Wb}.$$

This changes takes place in 1·5 ms.

$$\text{Therefore, the induced EMF} = -\left(2000 \times \frac{75 \times 10^{-6}}{1{\cdot}5 \times 10^{-3}}\right),$$

$$= \underline{-100\ \text{V}.}$$

Q13 *A conductor of length 15 cm is moved at 20 m/s at right angles to a magnetic field. If the induced EMF is 0·42 V, find the flux density of the field.* (*3 min*)

$$\textbf{A13}\quad \text{Flux density} = \frac{\text{induced EMF}}{\text{length of conductor} \times \text{velocity}},$$

$$= \frac{0{\cdot}42}{15 \times 10^{-2} \times 20},$$

$$= \underline{0{\cdot}14\ \text{Wb/m}^2.}$$

Q14 *Which magnetic law states that the direction of an induced EMF is such as to oppose the change that is producing it?* (*½ min*)

A14 Lenz's law.

Q15 *A transformer has a primary coil of 400 turns and a secondary coil of 25 turns. If the voltage across the terminals of the primary coil is 200 V, determine the voltage across the terminals of the secondary coil.* (*2 min*)

$$\textbf{A15}\quad \text{Secondary voltage} = \frac{25}{400} \times 200 = \underline{12{\cdot}5\ \text{V}.}$$

Q16 *Complete the following*

(*a*) *The amount of magnetic flux density remaining in a material after the magnetising force has been removed is known as the ....*

(*b*) *The phenomena of the changes in magnetic flux density lagging the magnetising force is known as ....*

(*c*) *In a transformer, the rise in temperature of the magnetic material is due to the effects of (i).........loss as a result of the (ii)......... effect.* (*1½ min*)

A16 (*a*) remanance.
(*b*) hysteresis.
(*c*) (*i*) energy
(*ii*) hysteresis

Q17 *An inductor of 80 mH carries a current of 2mA which is increased to 5mA in 40 μs. If the number of turns in the inductor is 800 determine the change in flux.* (*3 min*)

A17 Induced voltage, *E*,

= inductance × rate of change of current,

$$= 80 \times 10^{-3} \times \frac{3 \times 10^{-3}}{40 \times 10^{-6}},$$

$$= 6\ \text{V}.$$

$$\text{But,}\qquad E = N\frac{\mathrm{d}\Phi}{\mathrm{d}t},$$

where N is the number of turns and $\frac{\mathrm{d}\Phi}{\mathrm{d}t}$ is the rate of change of flux.

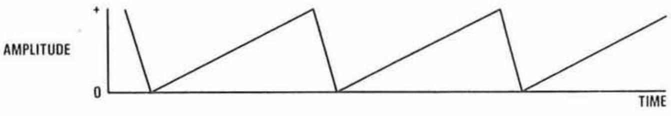
Therefore, the change of flux

$$= \text{the time period} \times \frac{E}{N},$$

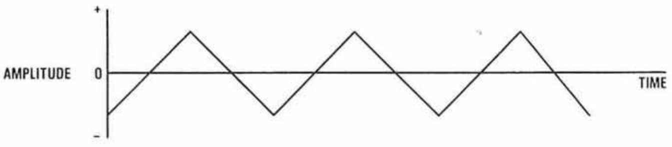
$$= \frac{40 \times 10^{-6} \times 6}{800}\ \text{Wb},$$

$$= \underline{0{\cdot}3\ \mu\text{Wb}.}$$

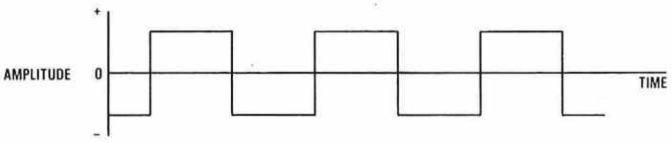
Q18 *Identify each of the waveforms shown below.* (*1 min*)



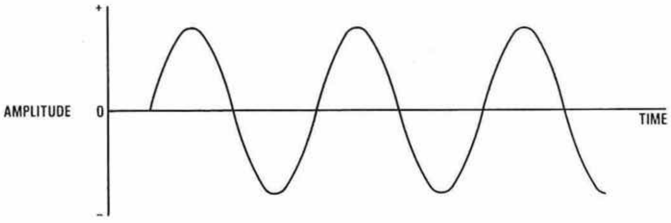
(*a*)



(*b*)



(*c*)

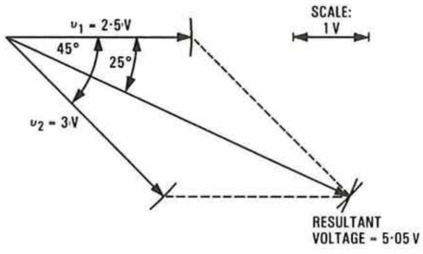


(*d*)

A18 (*a*) Sawtooth.
(*b*) Triangular.
(*c*) Square.
(*d*) Sinusoidal.

Q19 *Two sinusoidal voltages v_1 and v_2 have amplitudes of 2·5 V and 3 V, respectively, but v_2 is lagging by 45°. Both voltages have the same frequency. By using a scaled diagram, determine the amplitude and phase angle of $v_1 + v_2$.* (*3 min*)

A19 Phasors for v_1 and v_2 are shown in the sketch.



From the sketch, the amplitude of $v_1 + v_2$ is 5·05 V, lagging v_1 by 25°.

Q20 *A voltage waveform is expressed as*

$$v = 24 \sin (84\,834\,t)\ \text{volts},$$

where t is the time in seconds.

Determine

(*a*) *the peak voltage,*
(*b*) *the frequency,*
(*c*) *the instantaneous voltage at t = 25 μs, and*
(*d*) *the RMS value of the voltage.* (*5 min*)

A20 (*a*) The peak voltage = 24 V.

(*b*) The frequency $= \dfrac{84\,834}{2\pi}$ Hz = 13·5 kHz.

(*c*) The period of the wave $= \dfrac{1}{\text{frequency}}$,

$$= \frac{1}{13\,500}\ \text{s},$$

$$= 74\ \mu\text{s}.$$

A time of 74 μs is equivalent to an angle of 360°.
Therefore, 25 μs is equivalent to

$$\left(\frac{360}{74} \times 25\right) = 121{\cdot}6°.$$

Therefore, at 25 μs the instantaneous value of the wave is given by

$$v = 24 \sin 121{\cdot}6°,$$
$$= 24 \times 0{\cdot}8517,$$
$$= 20{\cdot}441\ \text{V}.$$

[*Tutorial note:* sin 121·6° is equivalent to sin 58·4°.]

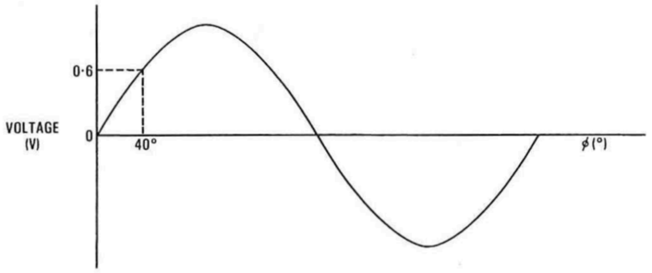
(*d*) RMS value = 24 × 0·707 = 16·97 V.

Q21 *For the sinusoidal waveform shown,*

(*a*) *calculate the peak value of the waveform;*

(*b*) *if the 40° reference point is equivalent to 0·02 ms, determine the frequency of the wave; and*

(*c*) *state the voltage level at* $\phi = 220°$. (*5 min*)



A21 (*a*) The instantaneous voltage, v, is given by

$$v = V_{\max} \sin \phi,$$

where $V_{\max}$ is the amplitude.

$$\therefore \quad 0{\cdot}6 = V_{\max} \sin 40°.$$

$$\therefore \quad V_{\max} = 0{\cdot}6 \times \frac{1}{\sin 40°},$$

$$= \frac{0{\cdot}6}{0{\cdot}643},$$

$$= 0{\cdot}93\ \text{V}.$$

(*b*) If $\phi = 40°$ corresponds to a time of 0·02 ms, then 360° corresponds to

$$\frac{360}{40} \times 0{\cdot}02 = 0{\cdot}18\ \text{ms}.$$

Therefore, the frequency $= \dfrac{1}{0{\cdot}18 \times 10^{-3}}$ Hz = 5·55 kHz.

(*c*) The 220° reference point is equivalent to the 40° reference point except that it is in the negative quadrant; therefore, the instantaneous voltage at $\phi = 220°$ is −0·6 V.

Q22 *A voltage wave, given by* $v = 30 \sin \omega t$, *is applied to a resistor of* 2·2 kΩ. *Determine the power dissipated in the resistor.* (*3 min*)

A22 The RMS value of the wave, V,

$$= 30 \times 0{\cdot}707 = 21{\cdot}21\ \text{V}.$$

The power dissipated in the resistor

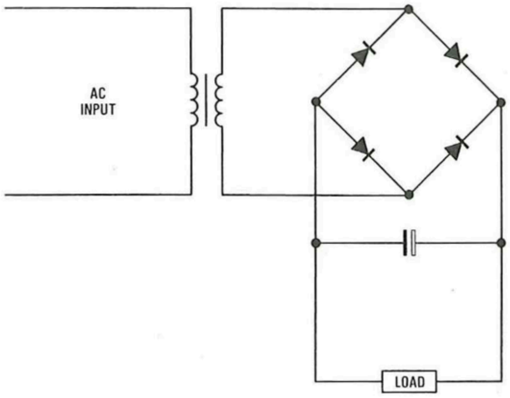
$$= \frac{V^2}{R} = \frac{21{\cdot}21^2}{2200} = 0{\cdot}204\ \text{W}.$$

Q23 *Complete the following:*
The current will (a).......... the voltage in an inductor.
The voltage across a capacitor will (b).......... the current. (*½ min*)

A23 (*a*) lag
(*b*) lag

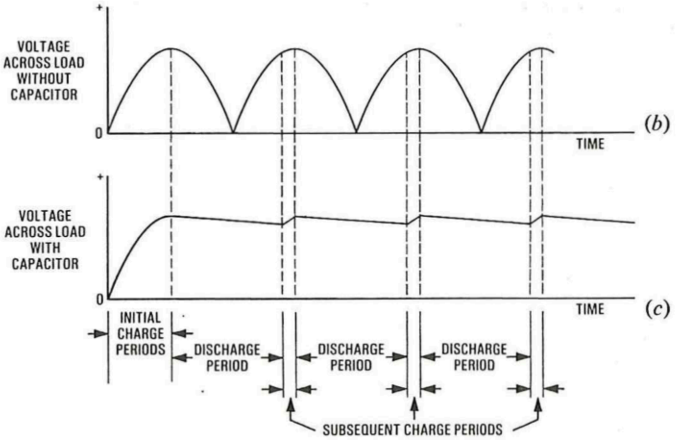
Q24 *Draw a bridge rectifier circuit, including a reservoir capacitor. Explain the action of the capacitor.* (*8 min*)

A24 The bridge rectifier circuit is shown in sketch (*a*).



(*a*)

Without the capacitor the bridge rectifier supplies a positive half sinusoidal voltage pulse every half cycle of the input waveform, as shown in sketch (*b*). When the capacitor is included in the circuit, it charges during the positive-going period of the voltage pulse and discharges, through the load, during the negative-going period of the pulse. If the component values are correctly chosen, the capacitor fully charges during the positive-going period of the wave, but only slowly discharges during the negative-going period of the wave. Each following pulse restores the capacitor to its fully-charged state. The capacitor therefore maintains the voltage across the load at a fairly constant level (see sketch (*c*)).



[*Tutorial note: Positive going* refers to a rising voltage and *negative going* refers to a falling voltage.]

Q25 *A sinusoidal voltage of frequency 8 kHz is applied across a pure capacitor of 2* μ*F. Determine the reactance of the capacitor.* (*2 min*)

A25 The reactance of the capacitor, X_c,

$$= \frac{1}{2\pi f C}\ \text{ohms},$$

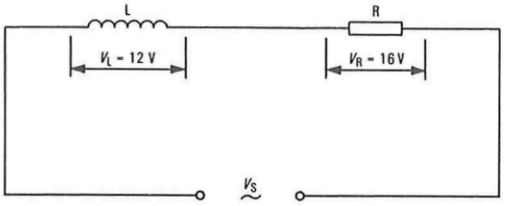
where f is the frequency and C is the capacitance.

$$\therefore \quad X_c = \frac{1}{2\pi \times 8 \times 10^3 \times 2 \times 10^{-6}} = 9{\cdot}95\ \Omega.$$

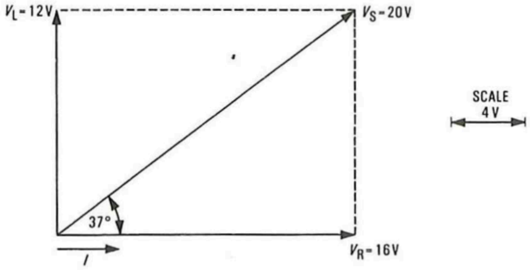
Q26 A DC supply of 10 V is applied across an inductor of 25 mH. If the resistance of the inductor is 250 Ω, determine the reactance of the inductor. (½ *min*)

A26 As the supply is DC, the reactance of the inductor is zero.

Q27 Refer to the circuit shown below. By drawing a scaled phasor diagram, determine the supply voltage and the phase angle. (4 *min*)



A27



From the diagram, the amplitude of V_S is 20 V, leading the current, I, by 37°.

Q28 A circuit consisting of an inductor, a capacitor and a resistor connected in series resonates at 60 kHz. If the value of the capactior is 0·4 μF, determine the value of the inductor. (3 *min*)

A28 At resonance the reactive impedances of the inductor and the capacitor are equal.

Therefore, $\omega L = \dfrac{1}{\omega C}$,

where $\omega = 2\pi \times$ frequency.

$$\therefore \quad L = \frac{1}{\omega^2 C} = \frac{1}{(2\pi \times 60 \times 10^3)^2 \times 0{\cdot}4 \times 10^{-6}}\,\text{H},$$

$$= \underline{0{\cdot}018\ \text{mH}}.$$

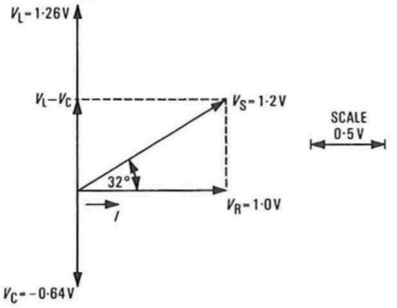
Q29 A circuit consisting of an inductor, a capacitor and a resistor connected in series is supplied with a current of 20 mA at 5 kHz. If L = 2 mH, C = 1 μF, R = 50 Ω, draw the voltage phasor diagram and from the diagram measure the value of the supply voltage and its phase angle. (8 *min*)

A29 The reactance of the inductor, X_L, is $2\pi fL$ ohms, where f is the frequency.

$$\therefore \quad X_L = 2\pi \times 5000 \times 2 \times 10^{-3} = 62{\cdot}83\ \Omega.$$

The reactance of the capacitor, X_C,

$$= \frac{1}{2\pi fC} = \frac{1}{2\pi \times 5000 \times 10^{-6}} = 31{\cdot}83\ \Omega.$$



The potential difference across L, V_L, is $I \times X_L$, where I is the current.

$$\therefore \quad V_L = \quad 20 \times 10^{-3} \times 62{\cdot}83 \quad = 1{\cdot}26\ \text{V}.$$

The potential difference across C, V_C, is given by

$$V_C = I \times X_C = \quad 20 \times 10^{-3} \times 31{\cdot}83 \quad = 0{\cdot}64\ \text{V}.$$

The potential difference across R, V_R, is given by

$$V_R = I \times R = \quad 20 \times 10^{-3} \times 50 \quad = 1{\cdot}0\ \text{V}$$

The phasor diagram is shown in the sketch.

From the diagram, the supply voltage, V_S, is 1·2 V, and the phase angle is 32°, with the voltage leading the current.

Q30 Two identical pure semiconductor segments are doped, one with a donor impurity, the other with an acceptor impurity. The 2 segments are then fused together and the resultant potential barrier developed between them is 0·7 V.

(a) State whether germanium or silicon has been used.

(b) List a typical donor impurity and a typical acceptor impurity.

(c) State the number of valence electrons in the pure material, the donor material and the acceptor material.

(d) Identify the doped segment which has a minority current carrier of holes.

(e) At room temperature, does the created device, when reverse biased, have an expected leakage current in the order of

(i) a few milliamperes,
(ii) a few microamperes, or
(iii) a few nanoamperes? (4 *min*)

A30 (*a*) Silicon.

[*Tutorial note:* As the potential barrier is given as 0·7 V, the material is silicon; germanium would give a value of 0·3 V, nominal.]

(*b*) Donor impurity: arsenic.
Acceptor impurity: boron.

(*c*) Pure semiconductor material: 4 valence electrons.
Donor impurity: 5 valence electrons.
Acceptor impurity: 3 valence electrons.

(*d*) The n-type material has a minority current carrier of holes; this is the segment doped with a donor impurity.

(*e*) As silicon has been used, the leakage current will be in the order of a few nanoamperes.

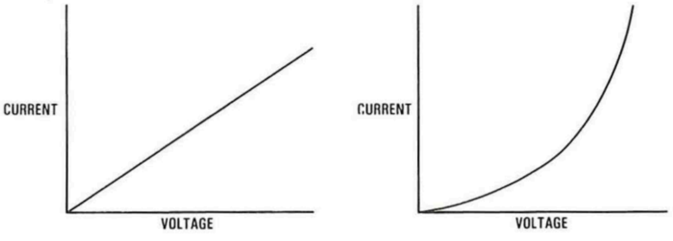
Q31 Use voltage/current graphs to illustrate the characteristic of

(a) a linear component, and

(b) a non-linear component.

Give an example of each. (2 *min*)

A31



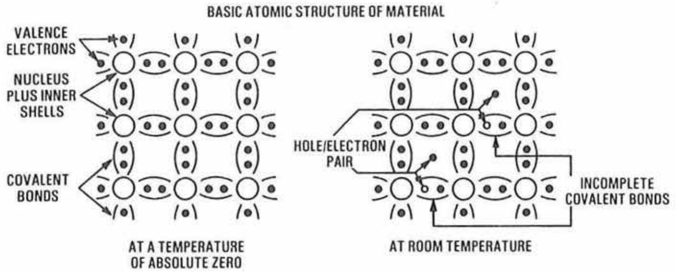
(*a*) (*b*)

Linear component: wire-wound resistor.
Non-linear component: diode.

Q32 Explain the term 'intrinsic conduction' as applied to semiconductors. (2 *min*)

A32 As the temperature of a semiconductor material increases, hole/electron pairs are generated. The flow of these holes or electrons is referred to as *intrinsic conduction.* Hole/electron pairs are created whenever a valence electron is given sufficient energy to break from its covalent bond.

[*Tutorial note:* This effect is shown in the sketch.]

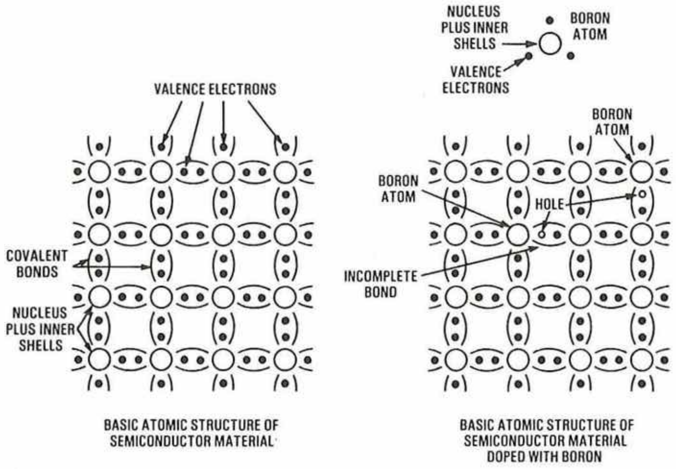

BASIC ATOMIC STRUCTURE OF MATERIAL
VALENCE ELECTRONS
NUCLEUS PLUS INNER SHELLS
COVALENT BONDS
HOLE/ELECTRON PAIR
INCOMPLETE COVALENT BONDS
AT A TEMPERATURE OF ABSOLUTE ZERO
AT ROOM TEMPERATURE

Q33 Explain, with the aid of diagrams, how a semiconductor material is created into a p-type material. The explanation is to be confined to the basic atomic structure of material. (*8 min*)

A33 A pure semiconductor material has 4 valence electrons per atom. The valence electrons of adjacent atoms form bonds which effectively hold the atomic structure of the material together (see sketch (*a*)).

Materials, such as boron, have 3 valence electrons. If a small amount of boron is infused into the semiconductor material, the bonding of some adjacent atoms would be incomplete, and thus holes would appear in the semiconductor's atomic structure (see sketch (*b*)). As the semiconductor material appears to have a deficiency of electrons, it is said to be *positive*; hence the term *p-type material.*

[*Tutorial note:* The doped material is still electrically neutral as the total electron count is equal to the total proton count within the material.]


VALENCE ELECTRONS
COVALENT BONDS
NUCLEUS PLUS INNER SHELLS
BASIC ATOMIC STRUCTURE OF SEMICONDUCTOR MATERIAL
NUCLEUS PLUS INNER SHELLS
VALENCE ELECTRONS
BORON ATOM
BORON ATOM
BORON ATOM
HOLE
INCOMPLETE BOND
BASIC ATOMIC STRUCTURE OF SEMICONDUCTOR MATERIAL DOPED WITH BORON

(*a*) (*b*)

Q34 How can a current waveform be displayed on an oscilloscope screen? (*5 min*)

A34 Oscilloscopes are devices for measuring voltage and time. If the waveform of a current flow is to be observed, then the probe leads of the oscilloscope must be connected across a resistor that is carrying the current. The voltage waveform displayed by the oscilloscope is a true representation of the current waveform as the current and the voltage waves for a resistor are always in phase with each other.

[*Tutorial note:* To determine the actual value of the current, the value of the resistor must be known.]

Q35 List the principal causes of error when moving-coil instruments are being used. (*5 min*)

A35 (*a*) Friction between moving parts.

(*b*) Temperature variations.

(*c*) Strong local magnetic fields.

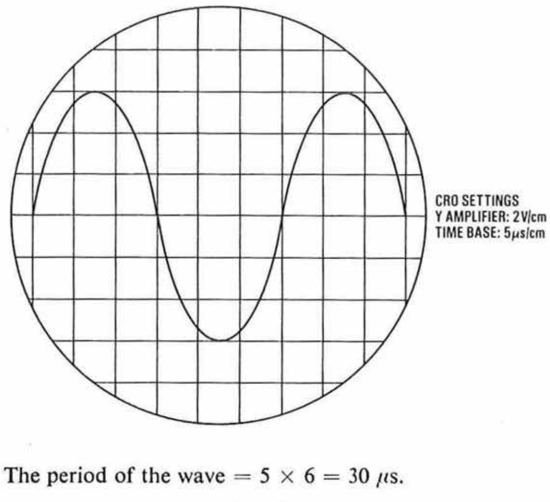
(*d*) An instrument for AC measurements is accurate only if the waveform is sinusoidal. Errors are introduced if this is not the case.

(*e*) The instrument is normally calibrated at 50 Hz; accuracy falls with increase in frequency.

(*f*) The instrument itself introduces errors. An ammeter must be connected in series with the monitored circuit, thus introducing additional resistance and causing the circuit current to fall.

(*g*) Incorrect usage by the operator.

Q36 Determine the frequency and the RMS value of the waveform shown below as a trace on a cathode-ray oscilloscope (CRO). (Assume that the lines on the scale are spaced 1 cm apart.) (*3 min*)



A36 The period of the wave $= 5 \times 6 = 30\ \mu s$.

Therefore, the frequency $= \dfrac{1}{30 \times 10^{-6}}$ Hz $= \underline{33\ \text{kHz}}$.

The peak value of the wave is 6 V; therefore, the RMS value

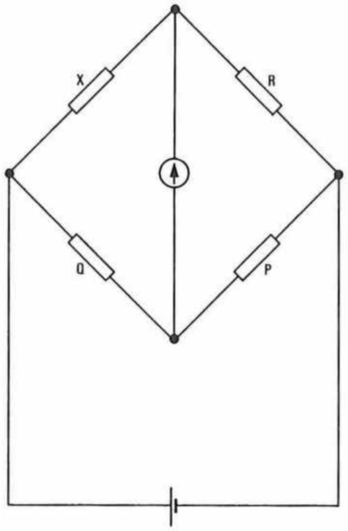
$$= 0{\cdot}707 \times 6 = \underline{4{\cdot}242\ \text{V}}.$$

[*Tutorial note:* A CRO display shows the time function relative to the horizontal and the amplitude function relative to the vertical. The waveform is always a voltage wave.]

Q37 The Wheatstone bridge shown below is balanced when $R = 15\ \Omega$, $P = 200\ \Omega$, and $Q = 1000\ \Omega$.

(*a*) *Determine the value of the resistor X.*

(*b*) *If the bridge is supplied by a 2 V battery, determine the voltage across X.* (*4 min*)



A37 (*a*) At balance,

$$X = \frac{RQ}{P} = \frac{15 \times 1000}{200} = \underline{75\ \Omega.}$$

(*b*) The total resistance of the upper branch

$$= X + R = 75 + 15 = 90\ \Omega.$$

The current in the upper branch $= \dfrac{2}{90}$ A.

Therefore, the potential difference across X

$$= \frac{2}{90} \times 75 = \underline{1{\cdot}67\ \text{V}.}$$

TEC: ELECTRICAL AND ELECTRONIC PRINCIPLES II (*continued*)

Q38 Why is damping necessary in moving-coil instruments? State 3 methods of damping. (*2 min*)

A38 Damping is necessary in order to prevent excessive oscillation of the instrument pointer, thus reducing the time taken for the pointer to assume a steady state.

Three methods of damping are

(*a*) eddy-current damping,

(*b*) air-friction damping, and

(*c*) liquid-friction damping.

Q39 A moving-coil instrument has a resistance of 25 Ω and needs a current of 5 mA to give full-scale deflection. Determine the value of the multiplier resistance required to give the instrument a range of 0–500 V. (*3 min*)

A39 The total resistance of the meter plus multiplier

$$= \frac{500}{5 \times 10^{-3}}\ \Omega = 100\ \text{k}\Omega.$$

Therefore, the multiplier resistance

$$= (100 \times 10^3) - 25\ \Omega = \underline{99{\cdot}075\ \text{k}\Omega.}$$

Q40 Complete the following.

In a cathode-ray oscilliscope the signal waveform to be observed is applied to the (a)..............plates and the time base signal is applied to the (b)..............plates. The brightness control signal is applied to the (c)..............and it has a (d).............. potential with respect to the cathode. (*1 min*)

A40 (*a*) Y plates

(*b*) X plates

(*c*) grid

(*d*) negative

Questions and answers contributed by N. C. Webber

TEC: MATHEMATICS II

TEC unit number U80/691. Students are advised to read the notes on p. 17

Q1 (*a*) *Given that the formula for the percentage change in voltage, v, is*

$$v = 100\left(1 - \frac{25}{v_1}\right),$$

draw up a table of values for v for values of v_1 from 40 to 50 inclusive in steps of 2.

(*b*) *Rearrange the formula* $f = \dfrac{1}{2\pi\sqrt{(LC)}}$ *to make L the subject.*

A1 (*a*)

v_1	40	42	44	46	48	50
$\frac{25}{v_1}$	0·625	0·595	0·568	0·543	0·521	0·5
$1 - \frac{25}{v_1}$	0·375	0·405	0·432	0·457	0·479	0·5
$100\left(1 - \frac{25}{v_1}\right)$	37·5	40·5	43·2	45·7	47·9	50·0

(*b*) The equation given is $f = \dfrac{1}{2\pi\sqrt{(LC)}}$.

Multiplying both sides of the equation by $\sqrt{(LC)}$, $f\sqrt{(LC)} = \dfrac{1}{2\pi}$.

Dividing both sides of the equation by f, $\sqrt{(LC)} = \dfrac{1}{2\pi f}$.

Squaring both sides of the equation, $LC = \dfrac{1}{4\pi^2 f^2}$.

Dividing both sides of the equation by C, $\underline{L = \dfrac{1}{4\pi^2 f^2 C}}$.

Q2 The current I amperes flowing through a circuit consisting of n cells, each having an EMF of E volts and an internal resistance of r ohms, connected in series, and an external resistance of R ohms is given by

$$I = \frac{nE}{R + nr}.$$

(*a*) *Rearrange the equation to make n the subject.*

(*b*) *Calculate the number of cells, n, if the current is 0·75 A; each cell has an EMF of 1·8 V and internal resistance 0·4 Ω; and the external resistance is 10 Ω.*

A2 (*a*) The equation given is

$$I = \frac{nE}{R + nr}.$$

Multiplying both sides of the equation by $(R + nr)$,

$$I(R + nr) = nE.$$

Expanding the bracket,

$$IR + Inr = nE.$$

Subtracting Inr from both sides of the equation,

$$IR = nE - Inr.$$

Factorising the right-hand side of the equation for n,

$$IR = n(E - Ir).$$

Dividing both sides of the above equation by $E - Ir$,

$$\frac{IR}{E - Ir} = n.$$

$$\therefore \quad \underline{n = \frac{IR}{E - Ir}}.$$

(*b*) Substituting the given values in the equation,

$$n = \frac{IR}{E - Ir} = \frac{0{\cdot}75 \times 10}{1{\cdot}8 - 0{\cdot}75 \times 0{\cdot}4},$$

$$= \underline{5.}$$

Q3 Calculate the values of a and b in the linear equation $y = ax + b$ for each of the following cases:

(*a*) *The line has a gradient of 3 and passes through the point (1, 6).*

(*b*) *The line passes through the points (1, −1) and (2, 1).*

A3 (*a*) The gradient of the line represented by the equation

$$y = ax + b$$

is a; therefore, from the information given, $a = \underline{3}$.

When $x = 1$, $y = 6$.

Therefore, substituting these values in the equation,

$$6 = (3 \times 1) + b = 3 + b.$$
$$b = 6 - 3 = \underline{3}$$

(*b*) When $x = 1$, $y = -1$.

When $x = 2$, $y = 1$.

Substituting both sets of values in the equation $y = ax + b$,

$$-1 = a + b, \text{ and} \qquad \ldots\ldots (1)$$
$$1 = 2a + b. \qquad \ldots\ldots (2)$$

Subtracting equation 2 from equation 1,

$$-2 = -a.$$
$$\therefore \quad a = \underline{2}.$$

Substituting for a in equation 1,

$$-1 = 2 + b.$$
$$\therefore \quad b = \underline{-3.}$$

Q4 An experiment was carried out to determine how the resistance, R, of a conductor varies with the temperature, T, of the conductor. The results obtained are shown in the following table.

R (ohms)	*4·2*	*4·36*	*4·5*	*4·78*	*5·02*	*5·25*	*5·5*	*5·6*
T (°C)	*16*	*25*	*35*	*50*	*65*	*80*	*95*	*100*

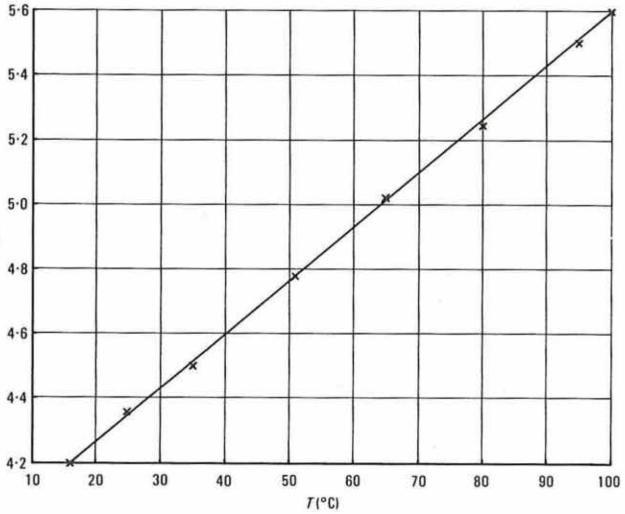
(*a*) *Draw a graph of suitable scale, plotting the resistance vertically and the temperature horizontally.*

(*b*) *Show that the graph is of the form $R = aT + b$, where a and b are constants.*

(*c*) *By using the co-ordinates of 2 points from the graph, calculate the values of a and b.*

(*d*) *Write down the law of the graph.*

A4 (*a*) The graph is shown in the sketch. A line is drawn as near to all the points as possible.



(*b*) The graph is a straight line; therefore, it is of the form

$$R = aT + b.$$

(*c*) Reading 2 sets of values for R and T from the graph, when $R = 5\cdot18$, $T = 75$, and when $R = 4\cdot4$, $T = 28$.

Substituting these values in the equation $R = aT + b$,

$$5\cdot18 = 75a + b, \text{ and} \qquad \ldots\ldots (1)$$
$$4\cdot4 = 28a + b. \qquad \ldots\ldots (2)$$

Subtracting equation 2 from equation 1,

$$0\cdot78 = 47a.$$

$$\therefore \quad a = \frac{0\cdot78}{47} = \underline{0\cdot0166}.$$

Substituting for a in equation 1

$$5\cdot18 = (75 \times 0\cdot0166) + b.$$

$$\therefore \quad b = 5\cdot18 - 1\cdot24 = \underline{3\cdot94}.$$

(*d*) The law of the graph is

$$\underline{R = 0\cdot017T + 3\cdot94}.$$

[*Tutorial Notes:* (*i*) The straight line was drawn to pass as close as possible to all the points on the graph. There is a small margin of choice, which may result in slightly different values of gradient.

(*ii*) To obtain the gradient of the straight line from the co-ordinates of 2 points on it, the points chosen should lie on the drawn line and should not include any plotted points (marked with a cross) unless such points are precisely on the line.

(*iii*) The points should be widely separated, to ensure greater accuracy, and can be chosen for ease of calculation.]

Q5 Solve the following simultaneous equations by using a graphical method (take values of V_1 from 0 to 4).

$$0\cdot9V_1 + 2\cdot7V_2 = 4\cdot2. \qquad \ldots\ldots (1)$$
$$1\cdot2V_1 - 1\cdot6V_2 = 1\cdot4. \qquad \ldots\ldots (2)$$

A5 From equation 1,

$$2\cdot7V_2 = 4\cdot2 - 0\cdot9V_1.$$

$$\therefore \quad V_2 = \frac{4\cdot2 - 0\cdot9V_1}{2\cdot7}.$$

Three values of V_2, for values of V_1 between 0 and 4, are given in the following table.

V_1	0	2	4
V_2	1·56	0·89	0·22

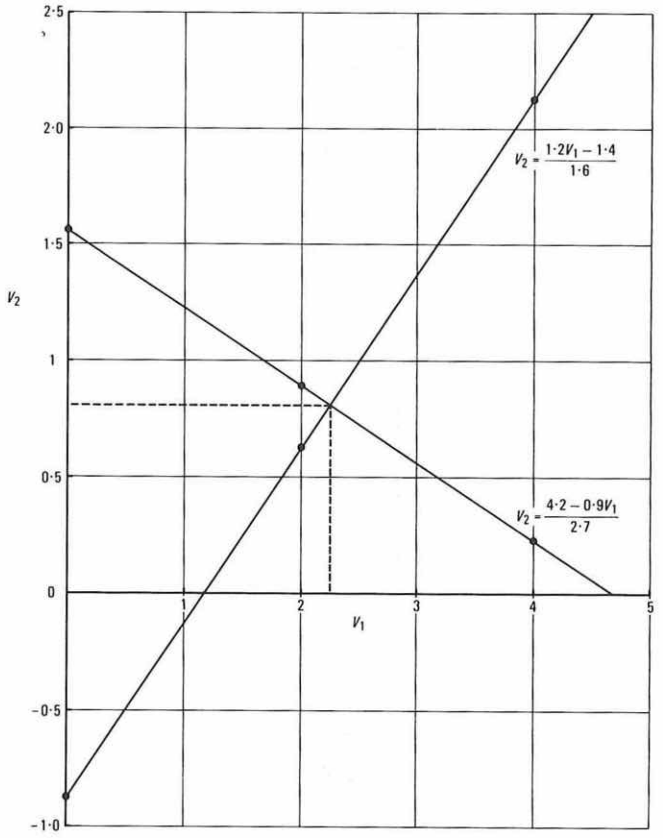
Similarly, from equation 2,

$$1\cdot6V_2 = 1\cdot2V_1 - 1\cdot4.$$

$$V_2 = \frac{1\cdot2V_1 - 1\cdot4}{1\cdot6}.$$

V_1	0	2	4
V_2	−0·875	0·625	2·125

The sketch shows these 2 sets of points plotted on a graph.



The solution to equations (1) and (2) is given by the point of intersection of the 2 lines.

Therefore, from the graph, $\underline{V_1 = 2\cdot25 \text{ and } V_2 = 0\cdot8}$.

Q6 (*a*) *Complete the following table.*

x	*−2*	*−1*	*0*	*1*	*2*	*3*
x^2	*4*				*4*	
$-x$				*−1*		
−2			*−2*			
$x^2 - x - 2$						*4*

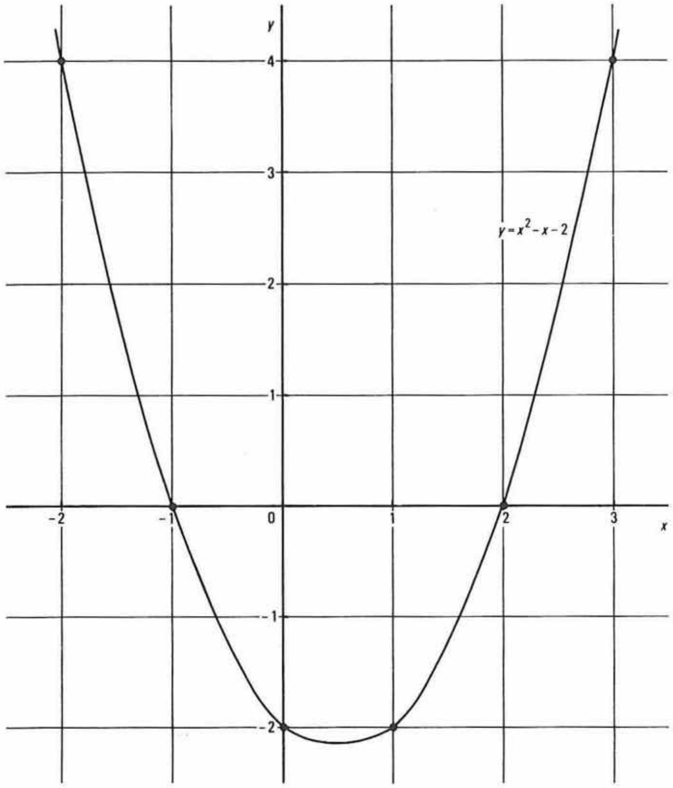
(*b*) *Plot the graph of $y = x^2 - x - 2$.*

(*c*) *From the graph solve the equation $x^2 - x - 2 = 0$.*

A6 (*a*)

x	-2	-1	0	1	2	3
x^2	4	1	0	1	4	9
$-x$	2	1	0	-1	-2	-3
-2	-2	-2	-2	-2	-2	-2
$x^2 - x - 2$	4	0	-2	-2	0	4

(*b*) See sketch.



(*c*) The solutions to the equation $x^2 - x - 2 = 0$ are the values of x where the curve crosses the x-axis.

Therefore, from the graph, $x = -1$ or $+2$.

Q7 Solve the following equations graphically taking values of x from −5 to +2.

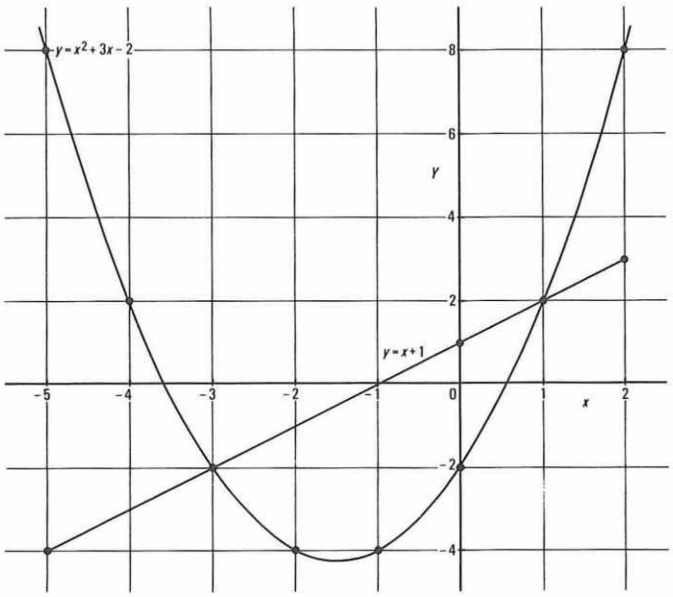
$$y = x + 1. \qquad \ldots\ldots (1)$$
$$y = x^2 + 3x - 2. \qquad \ldots\ldots (2)$$

A7 The graph of equation 1 can be plotted from the following table of values. [*Tutorial Note:* The equation is for a straight line; therefore only 3 values of x need be plotted.]

x	-5	0	2
$+1$	1	1	1
$y = x + 1$	-4	1	3

The graph of equation 2 can be plotted from the following table of values.

x	-5	-4	-3	-2	-1	0	1	2
x^2	25	16	9	4	1	0	1	4
$+3x$	-15	-12	-9	-6	-3	0	3	6
-2	-2	-2	-2	-2	-2	-2	-2	-2
$y = x^2 + 3x - 2$	8	2	-2	-4	-4	-2	2	8



The graphs of the 2 equations are shown in the sketch.

The solutions to these equations are the values of x and y at the points where the 2 graphs intersect.

Therefore, from the graph, the solutions are $x = 1,\ y = 2$ and $x = -3,\ y = -2$.

Q8 (a) Define a radian and draw a diagram to illustrate your definition.

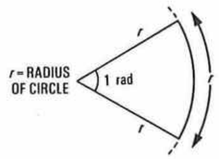
(b) Convert the following angles from degrees to radians giving the results as a fraction or multiple of π:

(i) 30°, (ii) 85°, and (iii) 120°.

(c) Convert the following angles from radians to degrees, without using a calculator:

(i) $\frac{\pi}{8}$ *rad, (ii)* $\frac{5\pi}{6}$ *rad, and (iii) 1·5 rad.*

A8 (*a*) A radian is the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle (see sketch).



(*b*) (*i*)

$$180^\circ = \pi \text{ rad.}$$
$$\therefore \quad 30^\circ = \frac{\pi}{6} \text{ rad.}$$

(*ii*)

$$180^\circ = \pi \text{ rad.}$$
$$\therefore \quad 1^\circ = \frac{\pi}{180} \text{ rad.}$$
$$\therefore \quad 85^\circ = \frac{85}{180} = \frac{17}{36}\pi \text{ rad.}$$

(*iii*)

$$180^\circ = \pi \text{ rad.}$$
$$120^\circ = \frac{120}{180}\pi = \frac{2}{3}\pi \text{ rad.}$$

(*c*) (*i*)

$$\pi \text{ rad} = 180^\circ.$$
$$\frac{\pi}{8} \text{ rad} = \frac{180}{8} = 22\tfrac{1}{2}^\circ.$$

(*ii*)

$$\frac{5\pi}{6} \text{ rad} = \frac{5 \times 180}{6} = 150^\circ.$$

(*iii*)

$$1 \text{ rad} = 57{\cdot}3^\circ.$$
$$1{\cdot}5 \text{ rad} = 57{\cdot}3 \times 1{\cdot}5,$$
$$= 85{\cdot}95^\circ \text{ or } 85^\circ\ 57'.$$

Q9 *The radius of the arc of a sector of a circle is 84 mm and the angle subtended at the centre of the circle is $\pi/6$ rad. Calculate,*

(*a*) *the length of the arc,*
(*b*) *the length of the chord, and*
(*c*) *the area of the sector.*

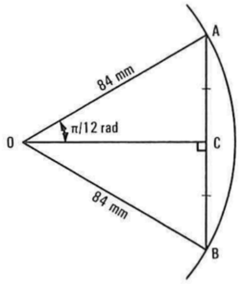
A9 (*a*) The length of the arc, l, is given by

$$l = r\theta,$$

where r is the radius of the circle and θ is the angle subtended at the centre of the circle in radians.

$$\therefore \quad l = 84 \times \frac{\pi}{6} = 14\pi = 43{\cdot}98 \text{ mm}.$$

(*b*) In the sketch AB is a chord and OA and OB are radii. Therefore, triangle OAB is isosceles. OC is perpendicular to AB and OC bisects AB.



Therefore, from triangle OAC, by using the sine ratio,

$$\sin\left(\frac{\pi}{12}\text{ rad}\right) = \frac{AC}{84}.$$

But,

$$\frac{\pi}{12}\text{ rad} = 15°.$$

$$\therefore \quad AC = 84 \sin 15°,$$
$$= 21{\cdot}74 \text{ mm}.$$

Therefore, the length of the chord

$$= 2 \times 21{\cdot}74 = \underline{43{\cdot}48 \text{ mm.}}$$

(*c*) The area of the sector, A, is given by

$$A = \tfrac{1}{2}r^2\theta,$$

where θ is measured in radians.

$$\therefore \quad A = \tfrac{1}{2} \times 84^2 \times \frac{\pi}{6},$$
$$= \underline{1847{\cdot}25 \text{ mm}^2.}$$

Q10 (*a*) *On the same axes and by using the same scale sketch the graphs of*

(*i*) $y = \sin\theta$, *and*
(*ii*) $y = \cos\theta$,

for a complete cycle. Label the graphs clearly.

(*b*) *Write down the relationship for* $\tan\theta$ *in terms of* $\sin\theta$ *and* $\cos\theta$.

(*c*) *By using the relationship given in part* (*b*) *and not by using tangent tables, obtain values of* $\tan 0°$, $\tan 45°$ *and* $\tan 90°$.

(*d*) *Sketch the graph of* $\tan\theta$ *for one complete cycle.*

A10 (*a*) The graphs are shown in sketch (*a*).

(*b*)

$$\tan\theta = \frac{\sin\theta}{\cos\theta}.$$

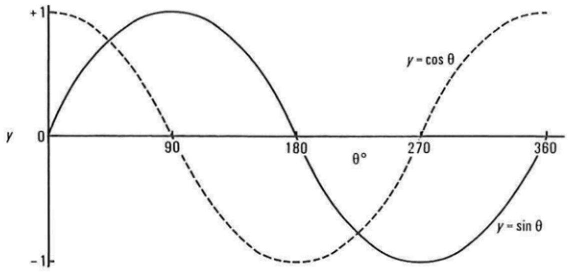
(*c*)

$$\begin{array}{lll} \sin 0° = 0 & \sin 45° = 0{\cdot}7071 & \sin 90° = 1 \\ \cos 0° = 1 & \sin 45° = 0{\cdot}7071 & \cos 90° = 0 \end{array}$$

$$\tan 0° = \frac{0}{1} = \underline{0.}$$

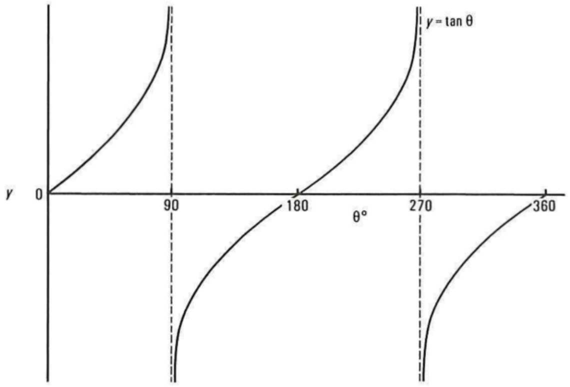
$$\tan 45° = \frac{0{\cdot}7071}{0{\cdot}7071} = \underline{1.}$$

$$\tan 90° = \frac{1}{0} = \underline{\infty.}$$



(*a*)

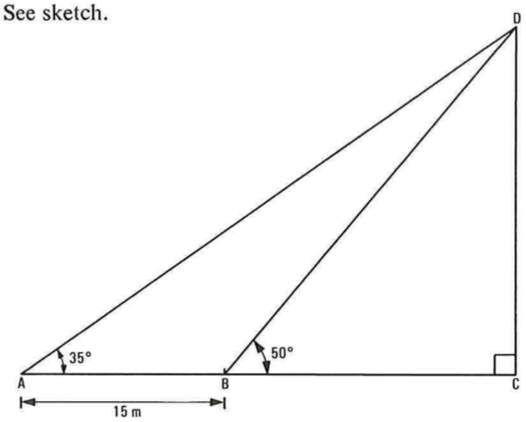
(*d*) The graph is shown in sketch (*b*).



(*b*)

Q11 *At a point on horizontal ground, the angle of elevation of the top of a vertical tower is 50°. At another point 15 m further from the foot of the tower, the angle of elevation is 35°. Calculate the height of the tower.*

A11 See sketch.



Since the angles on a straight line add up to 180°,

$$\angle ABD = 180° - 50° = 130°.$$

Therefore, since the angles of a triangle add up to 180°,

$$\angle ADB = 180° - 35° - 130° = 15°.$$

Using the sine rule

$$\frac{DB}{\sin \angle DAB} = \frac{AB}{\sin \angle ADB}.$$

$$\frac{DB}{\sin 35°} = \frac{15}{\sin 15°}.$$

$$\therefore \quad DB = \frac{15 \sin 35°}{\sin 15°},$$
$$= 33{\cdot}24 \text{ m}.$$

From triangle BCD

$$\sin 50° = \frac{DC}{33{\cdot}24}.$$

$$\therefore \quad DC = 33{\cdot}24 \times \sin 50°,$$
$$= 25{\cdot}46.$$

Therefore, height of the tower $= \underline{25{\cdot}46 \text{ m.}}$

Q12 *The heights of a group of boys were measured to the nearest centimetre. The results are classified in the following table.*

Height (cm)	*173*	*174*	*175*	*176*	*177*	*178*	*179*	*180*	*181*	*182*	*183*
Frequency	*40*	*62*	*80*	*88*	*90*	*60*	*45*	*35*	*20*	*7*	*3*

From these results,

(*a*) *draw a graph of cumulative frequency against height; and*

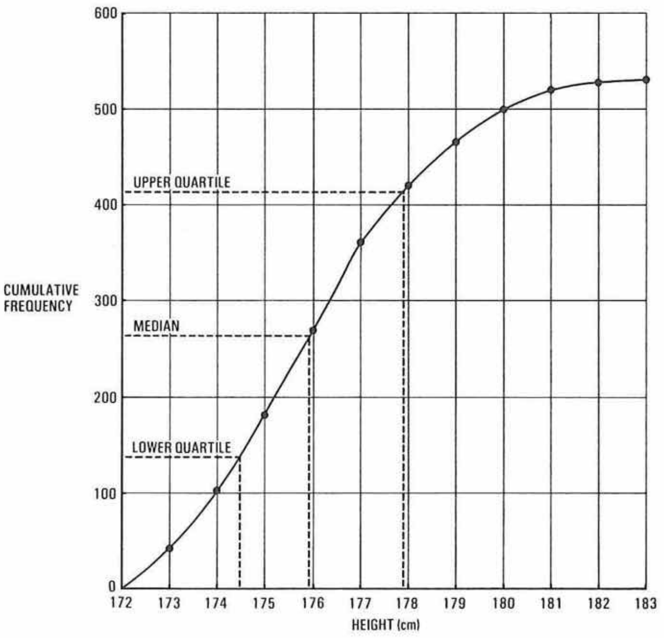
(*b*) *read off from the graph.*

(*i*) *the median,*
(*ii*) *the lower quartile, and*
(*iii*) *the upper quartile.*

A12 (*a*) The graph can be plotted from the following table.

Height (cm)	173	174	175	176	177	178	179	180	181	182	183
Cumulative Frequency	40	102	182	270	360	420	465	500	520	527	530

The graph is shown in the sketch.



(*b*) (*i*) The median is the height read from the graph for a cumulative frequency value of 530/2 = 265.

From the graph, the median is 175·9 cm.

(*ii*) [*Tutorial Note:* The quartiles are the values of the observations (heights in this case) that divide the distribution into quarters.]

The lower quartile is the height read from the graph for a cumulative frequency value of 530/4 = 137·5.

From the graph, the lower quartile is 174·5 cm.

(*iii*) The upper quartile is the height from the graph for a cumulative frequency value of $\frac{3}{4} \times 530 = 412\cdot5$.

From the graph, the upper quartile is 177·9 cm.

Q13 *For the following set of data*

8 7 9 6 8 6 2 6 5 4 7 6 1
4 7 7 8 3 6 5 2 8 6 5 4

(*a*) *calculate the mean,*

(*b*) *determine the median, and*

(*c*) *determine the mode.*

A13 (*a*)

$$\text{Mean} = \frac{\text{total of all the values}}{\text{number of values}} = \frac{140}{25},$$
$$= \underline{5\cdot6.}$$

(*b*) [*Tutorial Note:* The median is the value of the observation which divides the total frequency into 2 equal parts. If the observations are arranged in order of magnitude, the median is the central observation if the total number of observations is odd, and the arithmetic mean of the 2 central observations if the number of observations is even.]

Arranging the data in order of increasing order,

1 2 2 3 4 4 4 5 5 5 6 6 6
6 6 6 7 7 7 7 8 8 8 8 9

The number of values is odd; therefore, the median is the middle value: 6.

(*c*) The mode is the value that occurs the most often; therefore, the mode is 6.

Q14 *From the following frequency table*

(*a*) *calculate the mean, and*

(*b*) *calculate the standard deviation.*

x	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Frequency, f	*3*	*7*	*9*	*16*	*25*	*20*	*13*	*7*

A14 (*a*) See the following table.

x	f	fx
3	3	9
4	7	28
5	9	45
6	16	96
7	25	125
8	20	160
9	13	117
10	7	70
	$\Sigma f = 100$	$\Sigma fx = 700$

$$\text{Mean} = \bar{x} = \frac{\Sigma fx}{\Sigma f} = \frac{700}{100} = \underline{7.}$$

(*b*) See the following table of values.

x	f	$d = x - \bar{x}$	d^2	fd^2
3	3	−4	16	48
4	7	−3	9	63
5	9	−2	4	36
6	16	−1	1	16
7	25	0	0	0
8	20	1	1	20
9	13	2	4	52
10	7	3	9	63
	$\Sigma f = 100$		$\Sigma fd^2 = 298$	

$$\text{Standard deviation} = \sqrt{\left(\frac{\Sigma fd^2}{\Sigma f}\right)} = \sqrt{\left(\frac{298}{100}\right)},$$
$$= \underline{\pm1\cdot73.}$$

Questions and answers contributed by T. R. Sands

TEC: ELECTRONICS III

TEC unit number U81/743. Students are advised to read the notes on p. 17

A method of assessment that is sometimes used is demonstrated by this paper. Students would be expected to answer all the 10 questions in Section A and 3 out of the 4 questions in Section B. Students should allow approximately 60 min for completing Section A and 90 min for Section B.

SECTION A

Q1 By using the input characteristic shown in Fig. 1 determine the value of h_{ie} when the base bias current, I_B, is 20 μA. What change in base bias current is required to produce a smaller value of h_{ie}?

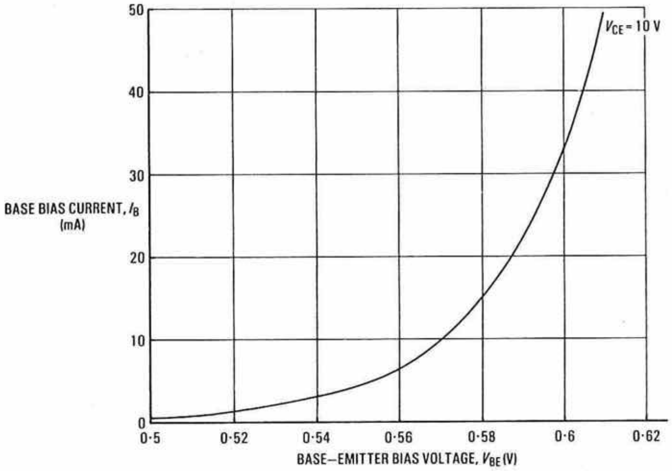
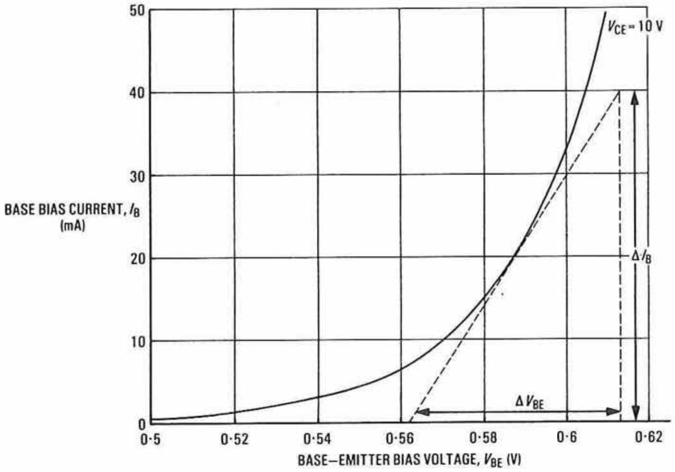


Fig. 1

A1 The value of h_{ie} required is the inverse of the slope of the tangent drawn to the curve at $I_b = 20 \mu A$.



Therefore, from the sketch,

$$h_{ie} = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{0 \cdot 613 - 0 \cdot 562}{(40 - 0) \times 10^{-6}},$$
$$= \underline{1275 \ \Omega.}$$

If h_{ie} is to be reduced, the slope at the operating point must be increased (since h_{ie} = 1/slope). It is necessary to increase the base current I_B to achieve this.

Q2 An n-channel depletion-type metal-oxide-semiconductor field-effect transistor (MOSFET) can operate in both depletion and enhancement modes.

Explain briefly the meaning of this statement.

A2 This type of MOSFET has an n-type channel between its source and drain when the gate potential is zero.

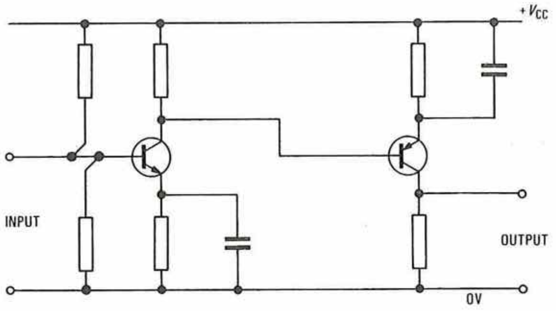
When the gate is made negative with respect to the source, free electrons are repelled from the channel, thus depleting the channel of charge carriers. This is depletion-mode operation, the conductance of the channel being reduced.

Enhancement-mode operation is when the charge-carrier content of the channel is increased. This is achieved by making the gate positive relative to the source, which attracts free electrons into the channel, thus increasing the conductance of the channel.

Q3 (a) Sketch a 2-stage direct-coupled amplifier using an n p n and a p n p transistor.

(b) State the difference expected in the frequency response of this amplifier compared to an RC-coupled amplifier.

A3 (*a*)



(*b*) The low-frequency response is better because of the absence of coupling capacitors.

Q4 The equivalent circuit of an amplifier is shown in Fig. 2, together with the test equipment required to measure the input and output impedances.

The following values were obtained during the measurement process.

$v_1 = 28$ *mV.* $\quad v_2 = 20$ *mV.*

$v_0 = 3$ *V when R is open circuit.*

$v_0 = 1 \cdot 5$ *V when R is set to* $4 \cdot 5$ *k*Ω.

Calculate the input and output impedances of this amplifier.

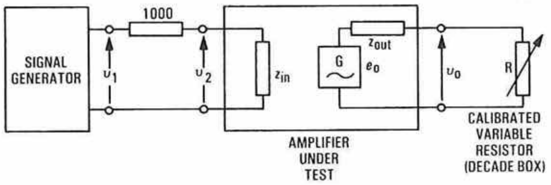


Fig. 2

A4 The input current, i_{in}, is given by

$$i_{in} = \frac{v_1 - v_2}{1000} = \frac{28 - 20}{1000} \text{ mA},$$
$$= \underline{0 \cdot 008 \text{ mA} = 8 \ \mu\text{A}.}$$

The input impedance, z_{in}, is given by

$$z_{in} = \frac{v_2}{i_{in}} = \frac{20 \times 10^{-3}}{8 \times 10^{-6}},$$
$$= \underline{2500 \ \Omega.}$$

When R is an open circuit $v_0 = e_0$; therefore $e_0 = 3$ V.
When R is 4500 Ω

$$v_0 = e_0 \times \frac{R}{z_{out} + R}.$$

$$\therefore \quad 1 \cdot 5 = \frac{3 \times R}{z_{out} + R}.$$

$$\therefore \quad 0 \cdot 5 = \frac{R}{z_{out} + R}.$$

$$\therefore \quad z_{out} + R = 2R.$$

$$\therefore \quad z_{out} = R.$$

$$\therefore \quad z_{out} = \underline{4500 \ \Omega.}$$

Q5 State the 2 main properties required of a buffer amplifier. Explain briefly why these properties are desirable.

A5 The 2 main properties are high input impedance and low output impedance.

Buffer amplifiers are required for isolating circuits that may be sensitive to varying load conditions; for example, in an oscillator as the output frequency is likely to be affected by load variations. The high input impedance provides only a light constant load for the sensitive circuit. The low output impedance is desirable to supply a wide range of load conditions without significant variation of the output voltage.

Q6 A 10 mV noise-free test signal is fed into the input of a communication channel. This channel has an overall gain of 26 dB and the output has a signal-to-noise ratio of 84 dB.

Calculate the noise voltage at the output.

(Assume the input impedance and the output load impedance of the channel are equal.)

A6 The voltage gain in decibels

$$= 20 \log_{10} \frac{v_{\text{out}}}{v_{\text{in}}},$$

where v_{out} is the output voltage of the channel and v_{in} is the input voltage.

$$\therefore \quad 26 = 20 \log_{10} \frac{v_{\text{out}}}{10 \times 10^{-3}}.$$

$$\therefore \quad 1{\cdot}3 = \log_{10} \frac{v_{\text{out}}}{10 \times 10^{-3}}.$$

$$\therefore \quad \frac{v_{\text{out}}}{10 \times 10^{-3}} = 20.$$

[*Tutorial note:* A reasonable approximation is to assume that $\log_{10} 2 = 0{\cdot}3$.]

$$\therefore \quad v_{\text{out}} = 200 \text{ mV}.$$

Signal-to-noise ratio in decibels

$$= 20 \log_{10} \frac{\text{signal voltage}}{\text{noise voltage}}.$$

$$\therefore \quad 84 = 20 \log_{10} \frac{200 \times 10^{-3}}{v_{\text{n}}},$$

where v_{n} is the noise voltage at the output.

$$\therefore \quad 4{\cdot}2 = \log_{10} \frac{200 \times 10^{-3}}{v_{\text{n}}}.$$

$$\therefore \quad \frac{200 \times 10^{-3}}{v_{\text{n}}} = 15\,849.$$

$$\therefore \quad \underline{v_{\text{n}} = 12{\cdot}6\ \mu\text{V}.}$$

Q7 An audio-frequency amplifier uses series voltage negative feedback. State the effect of this type of feedback on the following:

(*a*) *gain,*

(*b*) *gain stability,*

(*c*) *bandwidth,*

(*d*) *distortion,*

(*e*) *noise,*

(*f*) *input impedance, and*

(*g*) *output impedance.*

A7 (*a*) Reduced.

(*b*) Improved. Gain is determined to a significant degree by the feedback fraction.

(*c*) Increased, because of the gain reduction.

[*Tutorial note:* The gain-bandwidth product remains constant.]

(*d*) Reduced.

(*e*) Provided the noise is not present at the input of the amplifier it is reduced.

(*f*) Increased.

[*Tutorial note:* This is the effect of the feedback being applied in series with the input signal.]

(*g*) Reduced.

[*Tutorial note:* This is the result of how the feedback is produced in the output circuit.]

Q8 Explain briefly, the property of a quartz crystal known as the 'piezo-electric effect'.

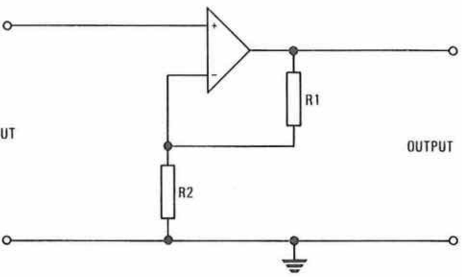
A8 When a quartz crystal is subjected to a mechanical stress, a potential difference is developed between opposite faces. A reversal of the stress reverses the polarity of the potential difference.

The opposite of this is also true; thus, the application of an alternating voltage across the crystal causes mechanical vibrations.

Q9 (*a*) *Sketch a simple non-inverting operational amplifier.*

(*b*) *Give an expression for the voltage gain of your amplifier.*

A9 (*a*)



(*b*) Voltage gain $= \dfrac{R_1 + R_2}{R_2}$.

Q10 The block diagram of a stabilised power supply is shown in Fig. 3. Explain briefly, how this arrangement corrects for an increase in the unregulated DC supply voltage.

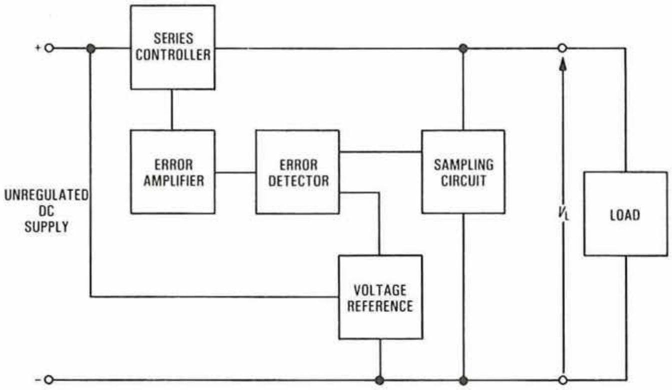


Fig. 3

A10 An increase in the unregulated supply voltage tends to cause an increase in V_L. The rise is detected by the sampling circuit, where it is fed to the error detector and compared with a reference voltage. The difference of the sampled voltage and the reference voltage is the output of the error detector. This is amplified and coupled to the series controller. In this case the conduction of the series controller is reduced, producing a larger voltage drop across the controller and correcting for the increase in the supply voltage.

SECTION B

Q11 During tests on a junction field-effect transistor, the output resistance was found to be in the region of 100 kΩ. The results shown in Table 1 were also recorded while the drain–source bias voltage, V_{DS}, was held constant.

This field-effect transistor is to be used in the amplifier circuit shown in Fig. 4, where r_{in} represents the input resistance of the next stage. The amplifier is required to operate with a gate–source bias voltage of $-2{\cdot}0$ V.

(*a*) *Estimate the following for this circuit condition:*

(*i*) *the value required for resistor R_S,*

(*ii*) *V_{DS},*

(*iii*) *the mutual conductance, g_m, and*

(*iv*) *the output voltage, v_o, when a 20 mV 1000 Hz test signal is applied to the input.*

(*b*) *What effect would an increase in the resistance of resistor R_S have on the output? Give reasons for your answer.*

Table 1

Gate-source bias voltage, V_{GS} (V)	*Drain current, I_D (mA)*
−1·5	*3·9*
−1·75	*3·16*
−2·0	*2·5*
−2·25	*1·91*
−2·5	*1·4*

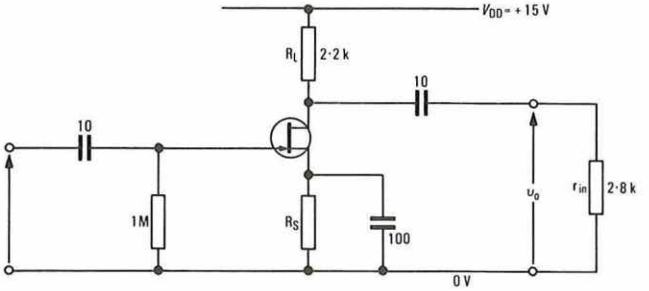


Fig. 4

A11 The high value of the output resistance indicates that V_{DS} has negligible effect on the drain current and can be disregarded in this example.

(*a*) (*i*) The required $V_{GS} = -2 \cdot 0$ V. From Table 1, $I_D = 2 \cdot 5$ mA.

$$R_s = \frac{V_{GS}}{I_D},$$
$$= \frac{2}{2 \cdot 5 \times 10^{-3}}\ \Omega,$$
$$= \underline{800\ \Omega.}$$

(*ii*)
$$V_{DS} = V_{DD} - I_D\,(R_S + R_L),$$
$$= 15 - 2 \cdot 5 \times 10^{-3}\,(800 + 2200),$$
$$= \underline{7 \cdot 5\ \text{V}.}$$

(*iii*)
$$g_m = \frac{\Delta I_D}{\Delta V_{GS}},$$

where ΔI_D is the small change in I_D consequent on a small change in V_{GS} (ΔV_{GS}).

The required operating condition is $V_{GS} = -2 \cdot 0$ V.

Therefore, considering changes of V_{GS} from $-1 \cdot 75$ to $-2 \cdot 25$ V in Table 1,

$$\Delta V_{GS} = 2 \cdot 25 - 1 \cdot 75 = 0 \cdot 5\ \text{V}.$$
$$\Delta I_D = 3 \cdot 16 - 1 \cdot 91 = 1 \cdot 25\ \text{mA}.$$
$$\therefore \quad g_m = \frac{1 \cdot 25 \times 10^{-3}}{0 \cdot 5}\ \text{S},$$
$$= \underline{2 \cdot 5\ \text{mS}.}$$

(*iv*) The total AC load to the amplifier, R_T, is the combined resistance of resistor R_L in parallel with resistor r_{in}.

$$\therefore \quad R_T = \frac{2 \cdot 2 \times 2 \cdot 8}{2 \cdot 2 + 2 \cdot 8}\ \text{k}\Omega,$$
$$= 1 \cdot 232\ \text{k}\Omega.$$

The amplifier gain, A_V is given by

$$A_V = -g_m R_T,$$
$$= -2 \cdot 5 \times 10^{-3} \times 1 \cdot 232 \times 10^3,$$
$$= \underline{-3 \cdot 08.}$$

[*Tutorial note:* The negative sign indicates a phase change of 180° between input and output.]

$$v_o = A_V \times v_{in},$$
$$= 3 \cdot 08 \times 20 \times 10^{-3}\ \text{V},$$
$$= \underline{61 \cdot 6\ \text{mV}.}$$

(*b*) A larger value for resistor R_S would produce a more negative gate-source bias voltage and thus a smaller drain current. Operating lower down on the mutual characteristic of the transistor reduces the mutual conductance. The voltage gain is consequently reduced, giving rise to a smaller output voltage.

Q12 *A complementary-pair class-B output stage is shown in Fig. 5.*

(*a*) *Explain, with the aid of a diagram, how cross-over distortion is minimised.*

(*b*) *Why is a matching transformer not required with this circuit?*

(*c*) *Explain how the DC potential at point A is stabilised at approximately $V_{CC}/2$.*

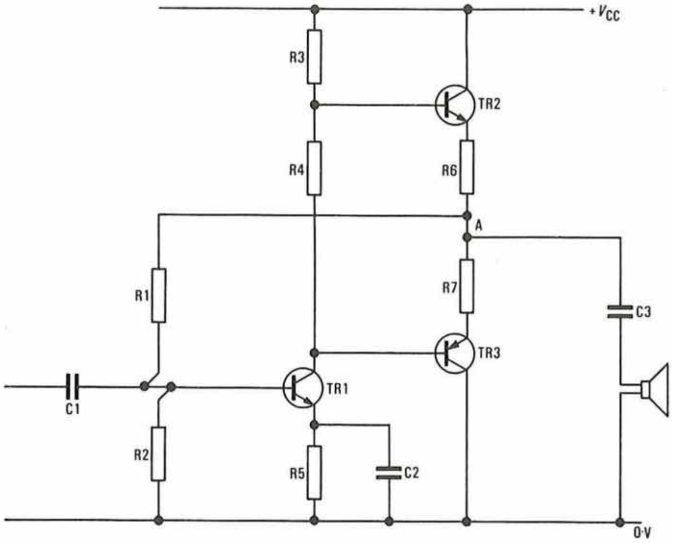


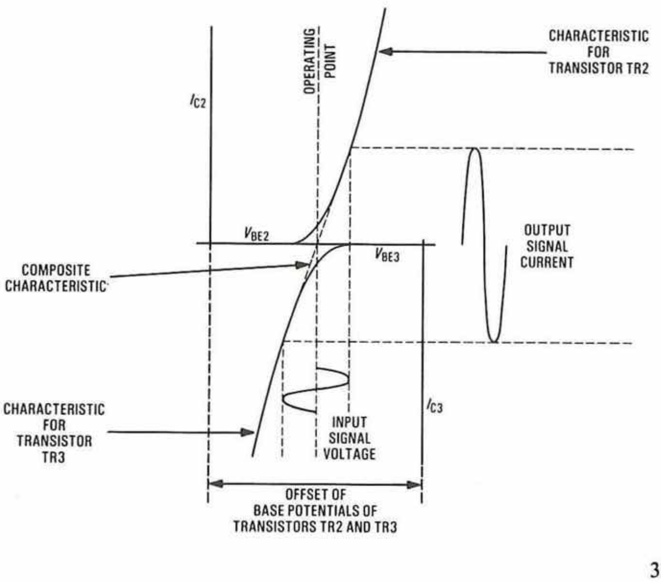
Fig. 5

A12 (*a*) Cross-over distortion occurs because of the excessive curvature of transistor characteristics at low values of current. The value of resistor R4 is chosen to offset the base potentials of transistors TR2 and TR3 sufficiently in the quiescent condition to produce small quiescent currents in the output transistors.

The relationship between the input signal voltage and output current is determined by the composite characteristic, which is relatively linear, consequently minimising distortion (see sketch).

[*Tutorial note:* In the sketch of the characteristics it is assumed that the emitters of transistors TR2 and TR3 are at the same potential. This is a reasonable assumption as resistors R6 and R7 are very low value resistors.]

(*b*) The output transistors, TR2 and TR3, are connected as emitter followers. The output impedance of an emitter follower is low, which makes it suitable for matching directly to a low impedance load (that is, a loudspeaker).


OPERATING POINT
CHARACTERISTIC FOR TRANSISTOR TR2
I_{C2}
V_{BE2}
V_{BE3}
OUTPUT SIGNAL CURRENT
COMPOSITE CHARACTERISTIC
CHARACTERISTIC FOR TRANSISTOR TR3
INPUT SIGNAL VOLTAGE
I_{C3}
OFFSET OF BASE POTENTIALS OF TRANSISTORS TR2 AND TR3

(*c*) Any fluctuations in the DC potential at A in the quiescent condition are corrected by DC negative feedback from A to the base of transistor TR1.

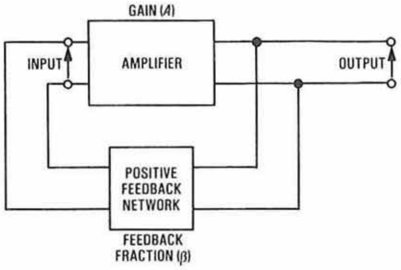
Consider the condition where the DC potential at A tends to rise. The increased potential is coupled by the potential divider consisting of resistors R1 and R2 to the base of transistor TR1. This results in an increase in the collector current of transistor TR1, causing the potentials at the bases of transistors TR2 and TR3 to decrease. The emitter potentials of both output transistors fall, so correcting for the tendency of the potential at point A to increase.

Q13 *(a) Show, with the aid of a block diagram, the condition required for sustained oscillations in an amplifier.*

(b) Draw the circuit diagram of an RC oscillator incorporating an operational amplifier. Explain the operation of this circuit.

A13 (*a*) The basic requirement is an amplifier that has positive feedback between its output and input circuits (see sketch (*a*)). Sustained oscillations occur when the loop gain > = + 1; that is,

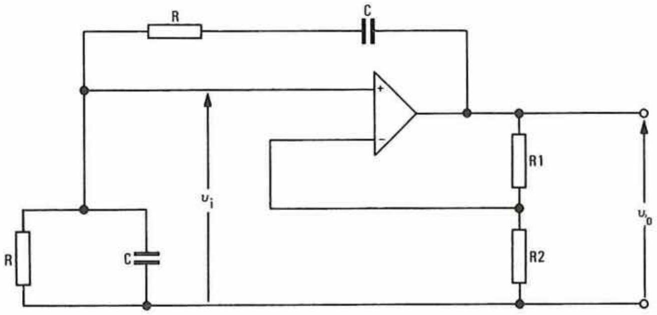
$$A\beta > = +1.$$



(*a*)

[*Tutorial note:* If A is negative (180° phase change between amplifier input and output), β must also be negative.]

(*b*) Sketch (b) shows a Wien bridge oscillator. The operational amplifier is used in its non-inverting application. The Wien circuit consists of the series and parallel RC combinations.



(*b*)

Oscillations occur at the frequency which experiences zero phase shift through the Wien network (v_i in phase with v_0). Provided the same values of R and C are used in the series and parallel networks, the following equation gives the frequency of oscillations, f:

$$f = \frac{1}{2\pi RC}\text{ hertz.}$$

The attenuation in the feedback network produces a feedback fraction (β) of $\frac{1}{3}$. In order to produce the necessary loop gain of unity, the gain of the operational amplifier, A, is 3.

$$A = \frac{R_1 + R_2}{R_2}.$$

$$\therefore \quad 3 = \frac{R_1 + R_2}{R_2}.$$

$$\therefore \quad 3R_2 = R_1 + R_2.$$

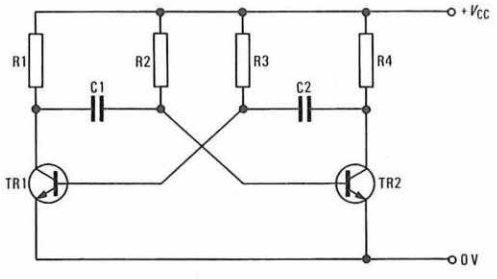
$$\therefore \quad R_1 = 2R_2.$$

Q14 *Explain, with the aid of circuit and waveform diagrams, the operation of an astable multivibrator.*

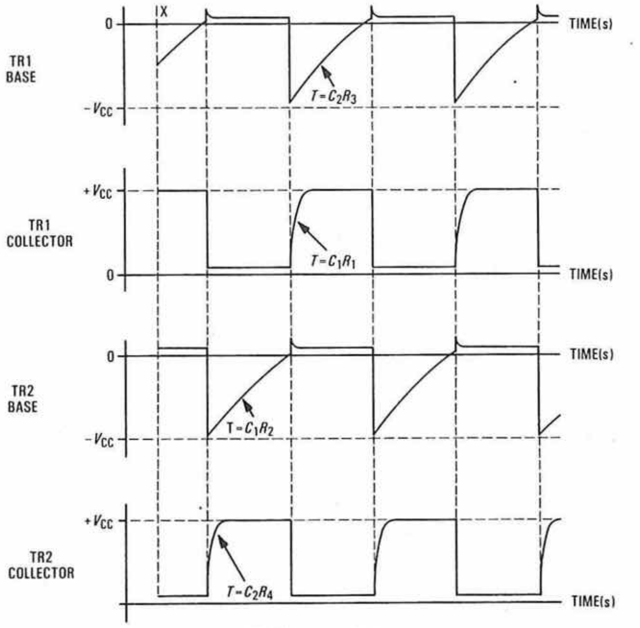
State the effect of the individual components on the shapes of the waveforms.

A14 Sketch (*a*) shows the circuit of an astable multivibrator, and sketch (*b*) shows the circuit waveforms.

Consider instant X with transistor TR1 cut off and transistor TR2 conducting heavily (saturation). The base potential of transistor TR1 is rising as capacitor C2 discharges through resistor R3 and transistor TR2. The conducting impedance of transistor TR2 is small compared with the value of resistor R3; consequently, the time constant of the discharge is C_2R_3. Transistor TR1 conducts when its base potential reaches about +0·6 V (assuming silicon transistors are being used). At the instant of changing state, capacitor C2 is almost fully discharged and capacitor C1 is charged to approximately V_{CC}.



(*a*)



T: Time constant

(*b*)

When transistor TR1 conducts, its collector potential falls. This fall in voltage is coupled by capacitor C1 to the base of transistor TR2 and causes transistor TR2 to cut off. Before the collector of transistor TR2 can rise to $+V_{CC}$, capacitor C2 must charge through resistor R4 and the base-emitter circuit of transistor TR1. The time constant of this charge is substantially C_2R_4. The total fall in potential at the collector of transistor TR1, and hence at the base of transistor TR2, is approximately V_{CC}. Transistor TR1 is now conducting heavily, while transistor TR2 is cut off.

Capacitor C1 now discharges through transistor TR1 and resistor R2 with a time constant of approximately C_1R_2. Transistor TR2 remains cut off until its base potential has risen sufficiently for transistor TR2 to conduct. The circuit again changes state and the action is repeated.

Capacitors C1 and C2 and resistors R2 and R3 determine the exponential rise of the base potentials of the transistors. Similarly, capacitors C1 and C2 and resistors R1 and R4 determine the rate at which the collector potentials rise.

The period of the waveform is approximately $0{\cdot}69(C_1R_2 + C_2R_3)$.

[*Tutorial note:* When a change of state occurs, the initial rise at the collector produces a rise on the base of the other transistor. The base potential then falls exponentially to its steady value, producing the spike shown on the waveform diagrams in sketch (*b*).]

Questions and answers contributed by C. Wright

TEC: LINES III

TEC unit number U81/756. Students are advised to read the notes on p. 17

Q1 *(a) State how cable faults can be generally classified.*

(b) With the aid of a diagram, explain how a double-end Varley test can be used to locate an incipient low-resistance fault on an unloaded 10 km length of quad trunk cable between terminal stations A and B.

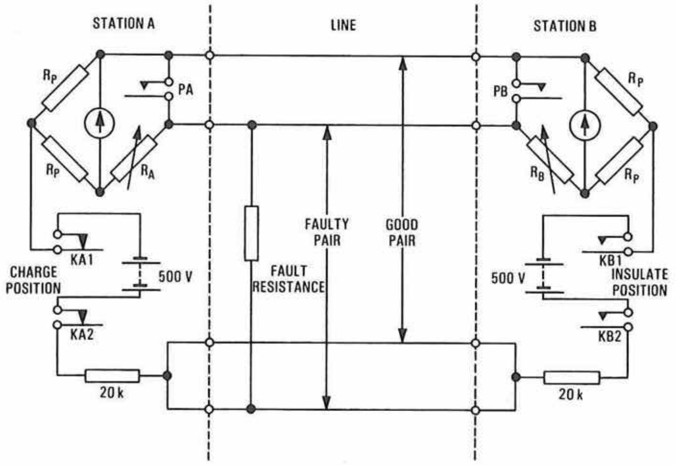
(c) If the variable resistances in the bridges at terminal stations A and B for the test in part (b) are 809·6 Ω and 190·4 Ω, respectively, calculate the distance to the fault.

(d) If a Murray bridge is connected to the good and faulty pairs at terminal B and the line is closed at terminal A, what would the ratio of the slide wire be at balance? *(25 min)*

A1 (*a*) Faults in cables can be generally classified as

(*i*) dielectric faults,
(*ii*) conductor faults, and
(*iii*) faults other than (*i*) or (*ii*) that affect transmission.

(*b*) Sketch (*a*) shows how the test apparatus should be set up.



(*a*)

Key PB is operated to close the line at station B. Key KB at station B is left at the insulate position and key KA at station A is operated to apply negative battery to charge the line. After the line has been allowed to charge up, the bridge resistor R_A at station A is adjusted to give a null deflection on the galvanometer (that is, to balance the bridge). When the bridge reading is stabilised, the value of R_A is recorded.

A similar test is then carried out from station B. Key PB at station B is released and the line is closed at station A by operating key PA. Key KA is set to the insulate position and a negative battery voltage is applied to the line by operating key KB. The bridge is balanced and the value of R_B recorded.

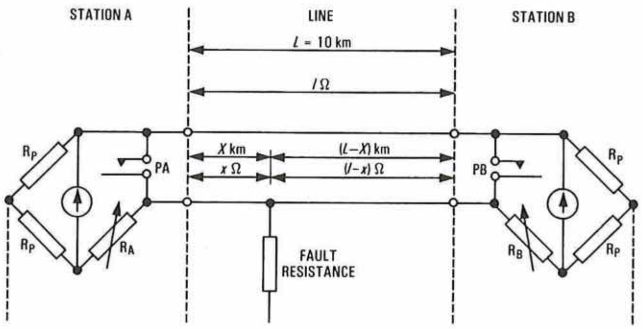
The tests should be repeated several times to obtain good mean values of R_A and R_B.

The distance (*X* kilometres) to the fault resistance, is calculated from the following formula

$$X = \left(\frac{R_B}{R_A + R_B}\right) L,$$

where *L* is the length of the cable tested in kilometres.

[*Tutorial note:* the above formula can be derived as follows. (See sketch (*b*).)



(*b*)

Assuming that the single-wire resistance of the good wire (l Ω) is equal to the single-wire resistance of the faulty wire, then, for the bridge at station A at balance,

$$R_A + x = (l - x) + l.$$

$$\therefore \quad R_A = 2l - 2x. \qquad \ldots\ldots (1)$$

Similarly, for station B at balance,

$$R_B + (l - x) = l + x. \qquad \ldots\ldots (2)$$

$$\therefore \quad R_B = 2x.$$

Dividing equation 1 by equation 2,

$$\frac{R_A}{R_B} = \frac{2l - 2x}{2x} = \frac{l - x}{x}.$$

$$\therefore \quad R_A x = R_B(l - x) = R_B l - R_B x.$$

$$\therefore \quad R_A x + R_B x = R_B l.$$

$$\therefore \quad x = \left(\frac{R_B}{R_A + R_B}\right) l.$$

The single-wire resistance of the line is directly proportional to the length of the line.

$$\therefore \quad X = \left(\frac{R_B}{R_A + R_B}\right) L.]$$

(*c*) Substituting $R_A = 809{\cdot}6\ \Omega$, $R_B = 190{\cdot}4\ \Omega$ and $L = 10$ km in

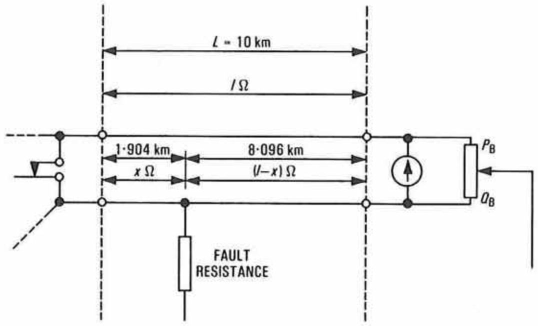
$$X = \left(\frac{R_B}{R_A + R_B}\right) L,$$

then

$$X = \left(\frac{190{\cdot}4}{809{\cdot}6 + 190{\cdot}4}\right) \times 10,$$

$$= \underline{1{\cdot}904 \text{ km}}.$$

(*d*) Sketch (*c*) shows the circuit when the Murray bridge is balanced.



(*c*)

At balance, the ratio of the slide wire, P_B/Q_B, is given by

$$\frac{P_B}{Q_B} = \frac{l + x}{l - x}.$$

Since the single-wire resistance of the line is directly proportional to the length of the line.

$$\frac{P_B}{Q_B} = \frac{L + X}{L - X},$$

$$= \frac{10 + 1{\cdot}904}{10 - 1{\cdot}904},$$

$$= 1{\cdot}47.$$

Hence, the ratio of the slide wire is $\underline{1{\cdot}47 : 1}$.

Q2 *A uniform transmission line of length 1 km has the following primary coefficients at 796 Hz:*

(i) resistance (R) = 50 Ω/km loop,
(ii) conductance (G) = 38 μS/km,
(iii) inductance (L) = 0·6 mH/km loop, and
(iv) capacitance (C) = 0·06 μF/km.

(a) Draw a diagram showing the line represented as a T network.

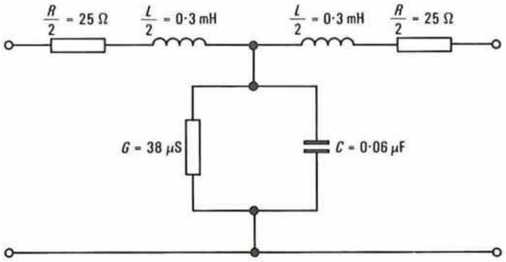
(b) Define the term 'characteristic impedance (Z_0)' of a uniform transmission line.

(c) If the line is correctly terminated, calculate the magnitude of Z_0.

(d) A low-loss coaxial cable, measured at 1 MHz, has the same values of inductance per kilometre loop and capacitance per kilometre as those given in part (a) for the uniform transmission line. Calculate the magnitude of Z_0, assuming that $\omega L \gg R$ and $\omega C \gg G$ (ω is $2\pi \times$ frequency).

(e) The low-loss coaxial cable in part (d) has a resistance per kilometre loop of 100 Ω and a conductance per kilometre of 300 μS at 1 MHz. Calculate the attenuation coefficient. *(20 min)*

A2 (*a*) The sketch shows the line represented as a T network.



$\frac{R}{2} = 25\ \Omega$
$\frac{L}{2} = 0{\cdot}3$ mH
$\frac{L}{2} = 0{\cdot}3$ mH
$\frac{R}{2} = 25\ \Omega$
$G = 38\ \mu$S
$C = 0{\cdot}06\ \mu$F

(*b*) The characteristic impedance of a uniform transmission line can be defined as the impedance measured at the sending end terminals of the line when the line is infinitely long or is terminated in an impedance equal to the characteristic impedance.

(*c*) The magnitude of the characteristic impedance, $|Z_0|$, is given by

$$|Z_0| = \sqrt[4]{\left(\frac{R^2 + \omega^2 L^2}{G^2 + \omega^2 C^2}\right)} \text{ ohms,}$$

where R is in ohms/kilometre, L is in henrys/kilometre, G is in siemans/kilometre and C is in farads/kilometre.

$$\therefore \quad |Z_0| = \sqrt[4]{\left(\frac{50^2 + (2\pi \times 796 \times 0{\cdot}6 \times 10^{-3})^2}{(38 \times 10^{-6})^2 + (2\pi \times 796 \times 0{\cdot}06 \times 10^{-6})^2}\right)},$$

$$= \sqrt[4]{\left(\frac{2500 + 9}{1444 \times 10^{-12} + 9 \times 10^4 \times 10^{-12}}\right)},$$

$$= \sqrt[4]{\left(\frac{2509 \times 10^{12}}{91444}\right)},$$

$$= \sqrt[4]{\left(\frac{2509}{9 \cdot 1444}\right)} \times \sqrt[4]{(10^8)},$$

$$= 4{\cdot}0699 \times 10^2,$$

$$= \underline{406{\cdot}99\ \Omega.}$$

(*d*) If $\omega L \gg R$ and $\omega C \gg G$, then

$$|Z_0| \approx \sqrt{\left(\frac{L}{C}\right)},$$

$$= \sqrt{\left(\frac{0{\cdot}6 \times 10^{-3}}{0{\cdot}06 \times 10^{-6}}\right)},$$

$$= \underline{100\ \Omega.}$$

(*e*) If $\omega L \gg R$ and $\omega C \gg G$, then the attenuation coefficient, α, is given by

$$\alpha \approx \frac{R}{2}\sqrt{\left(\frac{C}{L}\right)} + \frac{G}{2}\sqrt{\left(\frac{L}{C}\right)},$$

$$= \frac{R}{2|Z_0|} + \frac{G|Z_0|}{2},$$

$$= \frac{100}{2 \times 100} + \frac{300 \times 10^{-6} \times 100}{2},$$

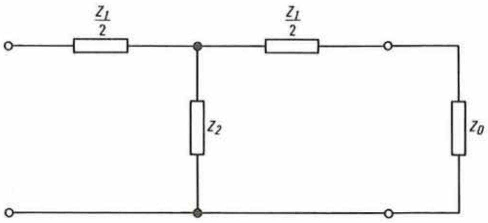
$$= 0{\cdot}5 + 0{\cdot}015,$$

$$= \underline{0{\cdot}515 \text{ Np/km.}}$$

Q3 *(a) List the secondary coefficients of a transmission line.*

(b) Define the term 'phase-change coefficient' as applied to a uniform transmission line.

(c) The sketch shows a short length of uniform transmission line represented by a T network with the far end of the line terminated in the characteristic impedance of the line (Z_0). If the input impedance is Z_0, derive a formula for Z_0 in terms of the series and shunt impedances.



(d) If the impedance measured at the sending end of a purely resistive short length of uniform transmission line is 1000 ∠0° Ω when the far end is open circuited, and 400 ∠0° Ω when the far end is short circuited, calculate the characteristic impedance of the line. *(15 min)*

A3 (*a*) The secondary line coefficients are:

(*i*) the characteristic impedance (Z_0),
(*ii*) the attenuation coefficient (α),
(*iii*) the phase-change coefficient (β), and
(*iv*) the velocity of propagation (V).

(*b*) The phase-change coefficient of a uniform line can be defined as the phase difference between the currents at the beginning and end of a 1 km section, the section being part of an infinite line or a finite line terminated in its characteristic impedance.

(*c*)

$$Z_0 = \frac{Z_1}{2} + \frac{\left(\frac{Z_1}{2} + Z_0\right) Z_2}{\frac{Z_1}{2} + Z_0 + Z_2}.$$

$$\therefore \quad \frac{Z_0 Z_1}{2} + Z_0^2 + Z_0 Z_2 = \frac{Z_1^2}{4} + \frac{Z_1 Z_0}{2} + \frac{Z_1 Z_2}{2} + \frac{Z_1 Z_2}{2} + Z_0 Z_2.$$

$$\therefore \quad \underline{Z_0 = \sqrt{\left(Z_1 Z_2 + \frac{Z_1^2}{4}\right)}.}$$

(*d*) The characteristic impedance of a transmission line can be expressed as

$$Z_0 = \sqrt{(Z_{OC} \times Z_{SC})},$$

where Z_{OC} is the input impedance of the line when it is open circuited at the far end, and Z_{SC} is the input impedance of the line when it is short circuited at the far end.

$$\therefore \quad Z_0 = \sqrt{(1000 \angle 0^\circ \times 400 \angle 0^\circ)},$$

$$= \underline{632{\cdot}46 \angle 0^\circ\ \Omega.}$$

Q4 *(a) Explain why the pulse-echo method is used for fault location.*

(b) With the aid of a block diagram, explain the pulse-echo method of fault location. *(25 min)*

A4 (*a*) The pulse-echo method for fault location is used for the following reasons:

(*i*) It is easy to use and faults due to impedance mismatch can be located quickly.

(*ii*) It is suitable for locating faults of varying DC and AC impedances.

(*iii*) It does not polarise corrosion-type faults.

(*iv*) The measurement, which is in units of time delay (usually microseconds), is readily converted into the distance to the fault.

(*v*) It is highly suitable for monitoring cable faults, including those due to failure of coaxial screens.

(*vi*) The display of the test equipment enables return pulse shapes due to connected equipment to be recognised.

(*vii*) Low-test-voltage tests on repeatered cables can be performed.

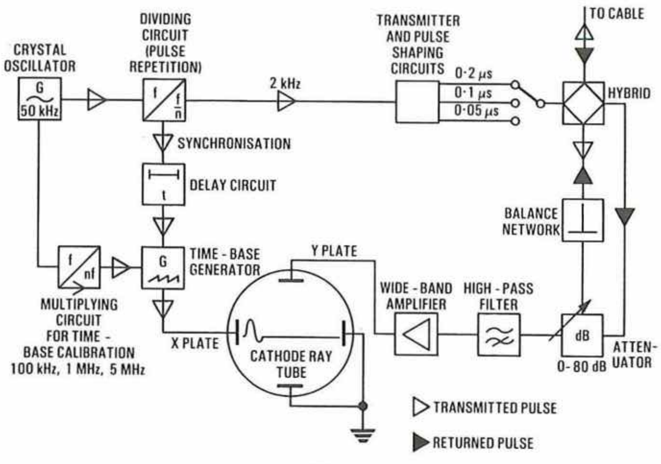
(*viii*) The type of fault can be ascertained.

(*b*) Sketch (*a*) shows a block diagram of the pulse-echo test equipment.

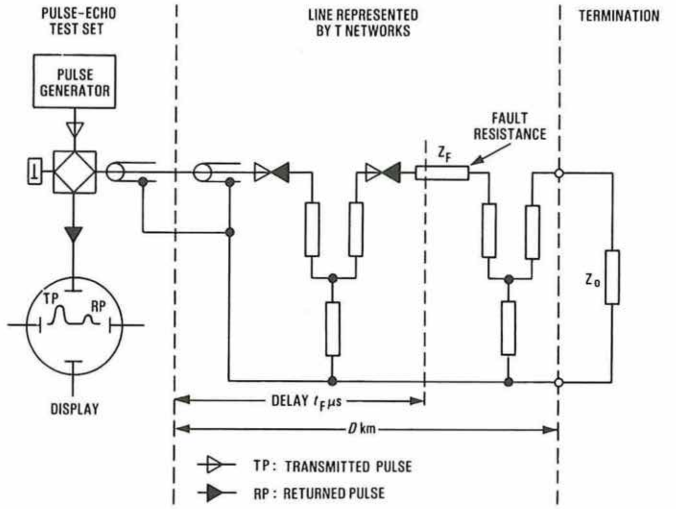
The principle of the pulse-echo method of fault location on coaxial cables depends on the reflection by the fault condition of an applied pulse transmitted from the test set. For example, a sine-squared pulse with an amplitude of 10 V might be transmitted into the test end of the cable. An attenuated pulse is reflected back to the sending end because of impedance irregularities or mismatch at the fault point.

The time delay between the transmission of the sent pulse at the test end and the reception of the reflected signal is measured on the timebase of the cathode-ray tube. As the speed of propagation of the pulse is constant in a cable of uniform construction, the measured time delay depends on the distance between the fault causing the reflection and the test end.

A fault that produces an increase of impedance at the fault point



(*a*)



(*b*)

produces a reflected pulse shape in the same direction as the incident pulse. Conversely, a fault that reduces the impedance at the fault point produces a pulse shape in the opposite direction of the incident pulse.

The duration of the pulse, which is indicated by the width, in microseconds, at half-pulse height, must be short enough to allow completion of the pulse transmission before any reflection is due to be returned from the nearest fault position.

The choice of a short-duration pulse allows greater sensitivity to be obtained; this allows smaller impedance irregularities to be observed. However, the high frequencies are attenuated, thus producing distortion. Therefore, the short-duration pulse is used for relatively short lengths of cable.

Sketch (*b*) illustrates the use of the pulse-echo test set in locating the position of an impedance irregularity.

Assuming that the pulse delay per kilometre is known and is equal to t_C µs/km (go and return), then if the measured delay to the fault impedance (Z_F) is t_F µs, the distance to the fault (D km) is given by t_F/t_C kilometres.

If t_C is unknown, then it can be obtained from measurements made on a known length of the same type of cable.

Q5 (*a*) *Explain what is meant by chemical corrosion.*

(*b*) *Explain what is meant by electro-chemical corrosion.*

(*c*) *List 5 forms of non-electrolytic corrosion.*

(*d*) *With the aid of a diagram, explain how potential measurements on a cable sheath are carried out by using a potentiometric voltmeter.*

(*e*) *With the aid of a diagram, explain how sheath-current measurements are carried out.* (*25 min*)

A5 (*a*) Chemical corrosion refers to corrosion in dry gases and non-electrolytes, where corrosion products are produced without the generation of an electric current.

(*b*) Electrochemical corrosion is corrosion resulting from the setting up of an electrochemical cell by the presence of material which is corroding and the surrounding electrolyte.

(*c*) (*i*) Differential aeration,

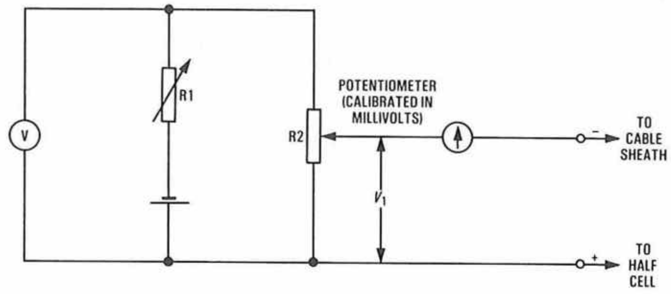
(*ii*) scratch corrosion,

(*iii*) corrosion due to dissimilar metals,

(*iv*) drop corrosion, and

(*v*) corrosion due to strong electrolytes.

(*d*) Sketch (*a*) shows the circuit of a potentiometric voltmeter that can be used to measure cable-sheath potential.



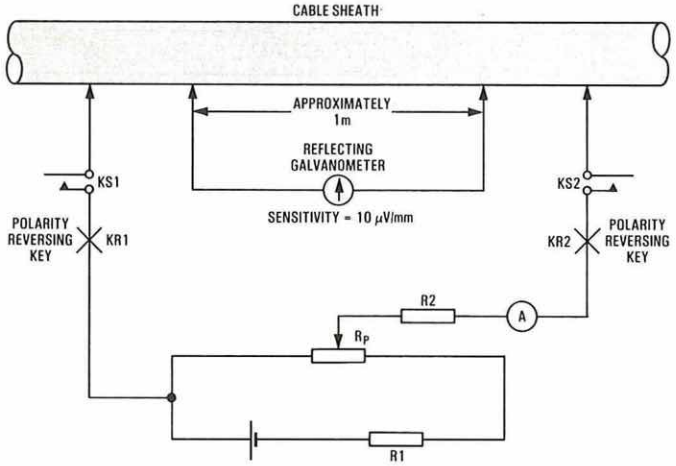
(*a*)

Variable resistance R1 is adjusted until a reading of 1·0 V is obtained on the voltmeter. The positive and negative terminals are then connected to the half cell and the cable sheath, respectively. The potentiometer (R2) is then adjusted until there is a zero reading on the galvanometer. At this point the potential V_1 is equal to the potential between the cable sheath and the half cell.

The half cell, which consists of a copper test electrode immersed in a saturated solution of copper sulphate, is used to ensure that reliable measurements are taken, as it minimises the junction potential between the electrode and the soil.

[*Tutorial note:* Potential measurements are made to find out whether the structure, at the point of testing, is cathodic or anodic to the surrounding soil or water.]

(*e*) Sketch (*b*) shows the circuit diagram of apparatus used for measuring cable-sheath current.



(*b*)

The magnitude of the current flowing is determined by measuring the potential difference across a length of cable sheath and converting this reading to a value of current using calibration factors.

The resistance of the galvanometer circuit should be sufficiently high to have negligible effect on the sheath current. The galvanometer is calibrated by passing a known current (typically 200 mA) through the cable sheath by operating key KS and adjusting variable resistor R_P. The galvanometer deflection, which is proportional to the sum or difference of the calibrating current and the normal sheath current, is noted. The direction of the calibrating current is reversed (using reversing key KR) and the deflection again noted.

The galvanometer deflection, d_1 in divisions, due to the known calibration current in one direction, together with the normal sheath current, is given by

$$d_1 = d_c + d_s \text{ divisions,}$$

where d_c is the deflection due to the calibration current and d_s is the deflection due to the sheath current.

Similarly, the galvanometer deflection, d_2, for the calibration current in the opposite direction is given by

$$d_2 = d_c - d_s \text{ divisions.}$$

The total swing, D, is given by

$$D = 2d_c \text{ divisions.}$$

The calibration factor in milliamperes/divisions is given by

$$\frac{2 \times \text{calibration current (in milliamperes)}}{D}.$$

After the galvanometer has been calibrated, the ammeter circuit is disconnected by key KS. The galvanometer reading indicates the magnitude and direction of the sheath current in milliamperes/division. [*Tutorial note:* Cable sheath current measurements are made during the investigation of electrolytic corrosion.]

Q6 (*a*) *Define the term 'capital-investment appraisal'.*

(*b*) *Compare the following costing terms:*

(*i*) *project cost,*
(*ii*) *direct cost,*
(*iii*) *indirect cost, and*
(*iv*) *inescapable cost.*

(*c*) *Define the term 'investment life'.*

(*d*) *Two capital projects, Beta and Saturn, have a costing period of 5 y. Compare the projects on the basis of cost only if the test discount rate is 8% and the costs are as follows.*

Project Beta Direct Costs

Year	*Labour* (£)	*Materials* (£)	*Expenses* (£)
1	*200*	*100*	*10*
2	*400*	*200*	*10*
3	*2000*	*1000*	*100*
4	*1000*	*500*	*100*
5	*200*	*100*	*10*

Project Saturn Direct Costs

Year	*Labour* (£)	*Materials* (£)	*Expenses* (£)
1	*200*	*100*	*20*
2	*2000*	*1000*	*100*
3	*1050*	*500*	*100*
4	*200*	*100*	*10*
5	*300*	*150*	*100*

For both projects the indirect costs each year are 10% of the direct costs. The present-value factors for a test discount rate of 8% are given in the following table.

Year	*1*	*2*	*3*	*4*	*5*
Present Value Factor	*0·926*	*0·857*	*0·794*	*0·735*	*0·681*

(*e*) *Show how the above present-value factors for a test discount rate are derived.* *(25 min)*

A6 (*a*) Capital-investment appraisal can be defined as the evaluation of capital projects for which funds have been especially set aside or committed.

(*b*) (*i*) Project costs are the total costs collected by the project cost centres. Within cost centres and cost units, costs can be further classified as the following cost elements: material costs, labour costs and expenses.

(*ii*) A direct cost is one which can be allocated directly as a whole item to a cost centre or cost unit.

(*iii*) An indirect cost cannot be attributed to a particular cost unit or cost centre but has to be apportioned on a suitable basis.

(*iv*) An inescapable cost is a direct or indirect cost that cannot be avoided.

(*c*) The investment life is the timespan over which the capital-investment appraisal of a project is made. It is determined by consideration of the project plant life. The investment life is shown as a number of periods of time (usually in years).

(*d*) The following tables show calculations of total present value (PV) for both projects.

Project Beta

Year	Total Direct Cost (£)	Indirect Cost (£)	Overall Cost (£)	PV Factor	PV (£)
1	310	31	341	0·926	315·8
2	610	61	671	0·857	575·0
3	3100	310	3410	0·794	2707·5
4	1600	160	1760	0·735	1293·6
5	310	31	341	0·681	232·2
			PV of project costs		5124·1

Project Saturn

Year	Total Direct Cost (£)	Indirect Cost (£)	Overall Cost (£)	PV Factor	PV (£)
1	320	32	352	0·926	326·0
2	3100	310	3410	0·857	2922·4
3	1650	165	1815	0·794	1441·1
4	310	31	341	0·735	250·6
5	550	55	605	0·681	412·0
			PV of project costs		5352·1

In this comparison Project Beta is more economic as it has the lowest PV of project costs.

(*e*) The net PV

$$= \frac{F_{v1}}{(1+i)^1} + \frac{F_{v2}}{(1+i)^2} + \ldots + \frac{F_{vn}}{(1+i)^n},$$

where F_{v1} is the net cash flow in the first period,

F_{v2} is the net cash flow in the second period,
F_{vn} is the net cash flow in the nth period, and i is the test discount rate.

Therefore, the net PV for a 5 year period

$$= \frac{F_{v1}}{1{\cdot}08} + \frac{F_{v2}}{1{\cdot}08^2} + \frac{F_{v3}}{1{\cdot}08^3} + \frac{F_{v4}}{1{\cdot}08^4} + \frac{F_{v5}}{1{\cdot}08^5}.$$

The PV factors are thus

$$\frac{1}{1{\cdot}08} = 0{\cdot}926; \ \frac{1}{1{\cdot}08^2} = 0{\cdot}857; \ \frac{1}{1{\cdot}08^3} = 0{\cdot}794;$$

$$\frac{1}{1{\cdot}08^4} = 0{\cdot}735; \text{ and } \frac{1}{1{\cdot}08^5} = 0{\cdot}681.$$

Q7 Write a well-organised essay (no more than 500 words) on a topic which demonstrates the need for supervision and efficient communication at the place of work. The essay should follow the plan outlined below:

- (*a*) *identify the problem,*
- (*b*) *state the objective,*
- (*c*) *break down the problem into its component parts,*
- (*d*) *refer to appropriate text books,*
- (*e*) *state what information is required,*
- (*f*) *analyse collected data, and*
- (*g*) *state a conclusion.*

(The assessment plan allocates a total of 6 hours preparation and study time for this project.)

A7 [*Tutorial note:* An outline example is given below.]

IMPROVING CABLE MAINTENANCE EFFICIENCY

The Problem

[*Tutorial note:* State which area requires change.]

Maintenance staff in a certain telephone area which covers a large country district take a long time to clear cable faults. On many occasions the maintenance test vehicles have to retrace their movements between their headquarters and cable test points. Some test vehicles arrive at the cable terminals without the appropriate test equipment and maintenance stores...

Project Objective

[*Tutorial note:* State the purpose of the project.]

This essay shows how proper supervision and efficient communications can provide the solution to the above problem...

Unanswered Questions

[*Tutorial note:* Define the problem area.]

The following will be considered:

(*a*) Is there proper supervision?
(*b*) How are the maintenance staff controlled?
(*c*) How effective is the communication between supervisor/control and staff?
(*d*) ...

Reference Material

[*Tutorial note:* Information may be obtained from appropriate references; for example, *Educational Pamphlets*, *British Telecommunications Engineering*, *British Telecom Journal*, British Telecom external-students-scheme learning packages, text books etc.]

Information Collected

Details of a specimen maintenance operation, movements and actual fault statistics are as follows...

Analysis of Data

Analysis of the collected information shows that the percentage of ineffective time is much higher than the national average. The length of time spent travelling for each fault is particularly high. Work study shows the need for improved communications...

Conclusion

In conclusion, the following recommendations are made:

(*a*) Radio communication equipment should be installed at the control and in the test vehicles.
(*b*) Supervisors should make more field visits.
(*c*) ...

Questions and answers contributed by D. C. Young.

SCOTTISH TECHNICAL EDUCATION COUNCIL

Certificate in Electrical and Electronic Engineering

The questions given below are from examination papers set by the Scottish Technical Education Council (SCOTEC) and are reproduced with the permission of the SCOTEC. The answers given have been prepared by independent authors. Sometimes, additional tutorial information is given; this is enclosed within square brackets to distinguish it from the information that would be expected of students under examination conditions. Answers to some questions are occasionally omitted because of insufficient space.

SCOTEC: ELECTRICAL PRINCIPLES III 1982

Students were expected to answer all questions in section A and 4 questions from section B. Because of space limitation some descriptive answers have been omitted.

SECTION A

Q1 Determine the dynamic impedance of the network shown in Fig. 1. *(4 marks)*

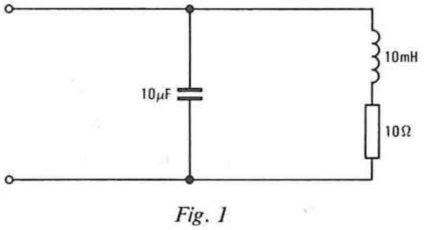


Fig. 1

A1 The dynamic impedance,

$$Z_r = \frac{L}{Cr} = \frac{10 \times 10^{-3}}{10 \times 10^{-6} \times 10} = \underline{100\ \Omega.}$$

Q2 Explain the reason that the load is not normally matched to the source in a power circuit. *(4 marks)*

A2 In a matched system, the efficiency of energy transmission would be only 50%, which is unacceptably low. Instead, the loading is a compromise to minimise losses.

Q3 For the network shown in Fig. 2, determine E_{RY}. (Express your answer in polar form.) *(4 marks)*

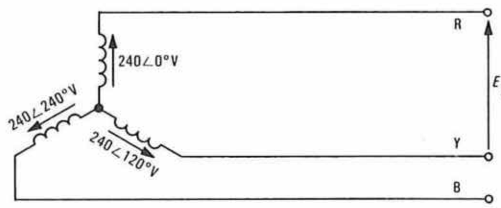


Fig. 2

A3

$$E_{RY} = 240\angle 0° + (-240\angle 120°),$$
$$= \underline{415\angle 30°\ \text{V}.}$$

Q4 After the switch in Fig. 3 is closed, what is the initial current in each of the branches. *(4 marks)*

A4 The current in the branch containing the capacitor is 10 A and in the branch containing the inductor, 0 A.

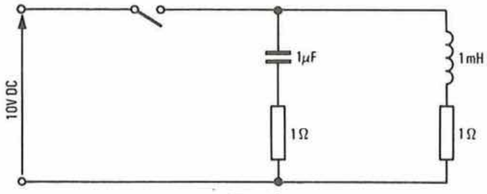


Fig. 3

Q5 *A 3 phase, 6 pole, 50 Hz induction motor is loaded to operate at 960 r/min. Calculate the slip.* (*6 marks*)

A5 If n_1 is the synchronous speed of the motor, f is the frequency and p is the number of pairs of poles, then

$$n_1 = \frac{f}{p} = \frac{50}{3} = 16{\cdot}67 \text{ r/s} = 1000 \text{ r/min.}$$

If n_r = the actual speed, then the slip,

$$s = \frac{n_1 - n_r}{n_1} = \frac{1000 - 960}{1000} = \underline{0{\cdot}04.}$$

Q6 *Determine the EMF, E, in the DC series motor shown in Fig. 4.* (*5 marks*)

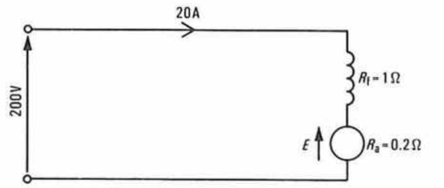


Fig. 4

A6 If V is the supply voltage and I the current, then

$$E = V - I(R_a + R_f) = 200 - 20(1 + 0{\cdot}2),$$
$$= \underline{176 \text{ V.}}$$

Q7 *Determine the current I in the network shown in Fig. 5.* (*6 marks*)

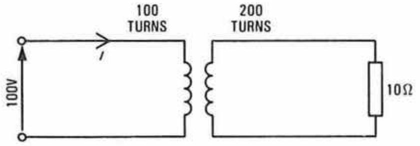


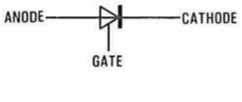
Fig. 5

A7 If V_1 is the voltage applied to the primary winding and N_1 and N_2 are the primary and secondary turns respectively, then

$$I = \frac{V_1}{(N_1/N_2)^2 Z_2} = \frac{100}{(100/200)^2 \times 10},$$
$$= \underline{40 \text{ A.}}$$

Q8 *Draw the symbol for a thyristor and label its terminals.* (*6 marks*)

A8



Q9 *State the expression for power gain of an amplifier.* (*3 marks*)

A9 $$G_p = \frac{P_o}{P_i} \text{ or } G_p = G_v G_i.$$

where G_p is the power gain, P_o is the output power, P_i is the input power, G_v is the voltage gain and G_i is the current gain.

Q10 *Explain how the electron beam in a cathode-ray tube is horizontally and vertically deflected.* (*8 marks*)

SECTION B (all questions carry 25 marks)

Q11 *With the aid of a suitable sketch, describe the construction of a thyristor.*

Explain how it is switched into the conducting state

(*a*) *by temporarily injecting current into the gate, and*

(*b*) *by leakage current causing the avalanche effect.*

What condition is essential to switch off a thyristor from the conducting state.

Q12 *A 2200 pF capacitor is connected in series with a 10 kΩ resistor through a switching transistor to a 10 V DC supply. The capacitor is initially discharged. Once the transistor is switched to the conducting state, determine*

(*a*) *the voltage/time characteristic of the capacitor,*

(*b*) *the voltage/time characteristic of the resistor, and*

(*c*) *from the characteristic, the time taken for the potential difference across the resistor to fall to 2 V.*

Neglect the internal resistance of the transistor.

The output of a transistor amplifier may be represented by a current generator shunted by a resistor as shown in Fig. 6. The load of the amplifier is shunted by a 1 kΩ bias resistor. Replace the network supplying the output terminals AB by a Norton equivalent network and hence determine the current in the 100 Ω load resistor.

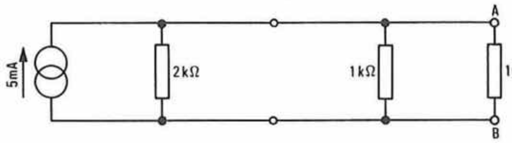
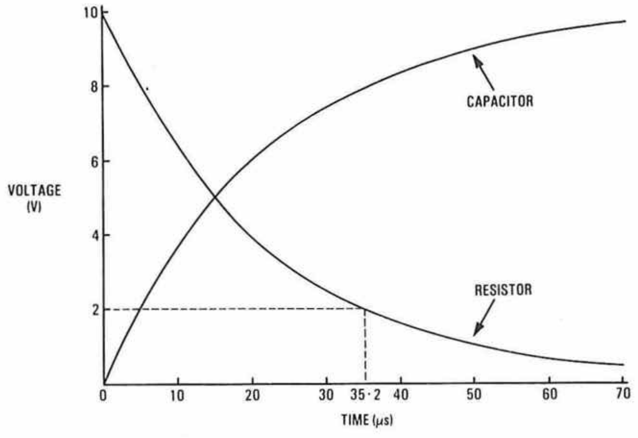


Fig. 6

A12 (*a*) (*b*) The characteristics are shown in the sketch.

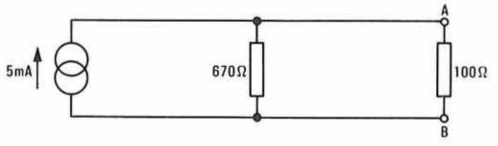


(*c*) The time taken for the potential difference to fall to 2 V is $\underline{35{\cdot}2\ \mu\text{s.}}$

The input resistance supplying terminals AB

$$= \frac{2 \times 1}{2 + 1} = 0{\cdot}67 \text{ k}\Omega = 670\ \Omega.$$

The equivalent circuit is shown in the sketch.



The current through the 100 Ω resistor

$$= \frac{670}{100 + 670} \times 5 = \underline{4{\cdot}4 \text{ mA.}}$$

Q13 *Describe the construction of a single-phase transformer and explain its principle of operation.*

A 100 kVA, single-phase transformer (assumed to be ideal) has a secondary voltage of 240 V. The primary winding has 1325 turns and the secondary winding has 50 turns. A 90 kW load with a power factor of 0·8 lagging is connected to the secondary terminals.

Determine

(*a*) *the primary voltage,*
(*b*) *the primary current,*
(*c*) *the reactive power supplied, and*
(*d*) *the overload at which the transformer is operating.*

A13 (*a*) The primary voltage

$$= \frac{1325}{50} \times 240 = \underline{6360\ \text{V}.}$$

(*b*) The secondary current

$$= \frac{90\,000}{240 \times 0{\cdot}8} = 470\ \text{A}.$$

Therefore the primary current

$$= \frac{50}{1325} \times 470 = \underline{17{\cdot}7\ \text{A}.}$$

(*c*) The reactive power supplied

$$= \frac{90\,000}{0{\cdot}8} \times 0{\cdot}6 = \underline{67{\cdot}5\ \text{kvar}.}$$

(*d*) The reactive load

$$= \frac{90\,000}{0{\cdot}8} = 112\,500\ \text{VA}.$$

Therefore the overload

$$= 112\,500 - 100\,000 = 12\,500\ \text{VA},$$
$$= \underline{12{\cdot}5\ \text{kVA}.}$$

Q14 *Sketch a B/H characteristic for a typical ferromagnetic material. Explain the concept of the relationship between the magnetic field strength, H, and the flux density, B, in terms of relative permeability, and hence sketch a μ/H characteristic.*

An induction motor is loaded to give an output torque of 89 N m at a rotational speed of 960 min. The line current from the 415 V 3-phase supply is 20 A at a power factor of 0·81 lagging. Calculate the efficiency of the motor.

By means of a capacitor bank connected in parallel with the motor, the power factor is improved to 0·95 lagging. If the load on the motor remains unchanged, again determine the efficiency of the motor and explain your answer.

A14 [For the first part of the question refer to a standard textbook.]

$$\text{Efficiency, } \eta = \frac{M\omega}{\sqrt{3}VI\cos\phi}$$

where M is the torque in newton metres, ω is the angular velocity in radians/second, V is the supply voltage, I is the supply current and $\cos\phi$ is the power factor.

$$\therefore \quad \eta = \frac{89}{\sqrt{3} \times 415 \times 20 \times 0{\cdot}81} \times \frac{960 \times 2\pi}{60},$$
$$= \underline{0{\cdot}77.}$$

When the power factor is improved, the current drawn from the supply will decrease and, hence, the efficiency will be unchanged. The change of power factor does not change the active power.

Q15 *In an experiment with an air-cored coil, the following voltmeter and wattmeter readings were recorded:*

(*a*) *DC test: voltmeter across the coil reads 24 V and the wattmeter reads 48 W for the power taken by the coil from the supply,*

(*b*) *50 Hz AC test: the corresponding readings were voltmeter 222 V and wattmeter 432 W.*

Determine

(*i*) *the resistance of the coil,*
(*ii*) *the inductance of the coil, and*
(*iii*) *the power factor of the AC test.*

If a capacitor of 29·5 μF is connected in series with the coil to the same 220 V 50 Hz supply, determine:

(*iv*) *the new value of the active power taken from the supply, and*
(*v*) *the new power factor, indicating whether the current lags or leads the voltage.*

A15 (*i*) The resistance of the coil is given by

$$R = \frac{V_{\text{DC}}^2}{P_{\text{DC}}^2},$$

where V_{DC} is the applied voltage and P_{DC} is the power for the DC test.

$$\therefore \quad R = \frac{24^2}{48} = \underline{12\ \Omega.}$$

(*ii*) For the AC test, the current is given by

$$I_{\text{AC}} = \sqrt{\frac{P_{\text{AC}}}{R}} = \sqrt{\frac{432}{12}} = \underline{6\ \text{A},}$$

where P_{AC} is the wattmeter reading for the AC test.

$$\text{Therefore the impedance } Z = \frac{V_{\text{AC}}}{I_{\text{AC}}} = \frac{222}{6},$$
$$= 37\ \Omega.$$

The inductive reactance is given by

$$X_{\text{L}} = \sqrt{(Z^2 - R^2)} = \sqrt{(37^2 - 12^2)},$$
$$= \sqrt{1225} = 35\ \Omega.$$

Therefore, the inductance L

$$= \frac{X_{\text{L}}}{2\pi f} = \frac{35}{100\pi} = \underline{0{\cdot}11\ \text{H}.}$$

(*iii*) The power factor is given by

$$\cos\phi = \frac{P_{\text{AC}}}{V_{\text{AC}}I_{\text{AC}}} = \frac{432}{222 \times 6},$$
$$= \underline{0{\cdot}32\ \text{lagging}.}$$

(*iv*) The capacitive reactance is given by

$$X_{\text{c}} = \frac{1}{2\pi fC}$$

where f is the frequency and C is the capacitance in farads.

$$\therefore \quad X_{\text{c}} = \frac{1}{2\pi \times 50 \times 29{\cdot}5 \times 10^{-6}} = \underline{108\ \Omega.}$$

The impedance of the combination, Z_1

$$= \sqrt{[R^2 + (X_{\text{L}} - X_{\text{C}})^2]},$$
$$= \sqrt{[12^2 + (35 - 108)^2]} = 74\ \Omega.$$

The current, I, drawn from the supply

$$= \frac{V_{\text{AC}}}{Z_1} = \frac{222}{74} = 3\ \text{A}.$$

The power, P,

$$= I_{\text{AC}}R = 3^2 \times 12 = \underline{108\ \text{W}.}$$

(*v*) The power factor $\cos\phi_1$ is given by $\frac{R}{Z} = \frac{12}{74} = \underline{0{\cdot}16\ \text{leading}.}$

Q16 *State* TWO *advantages of raising the power factor of an industrial load and give a reason why it is unusual in practice to raise the overall power factor of industrial loads to unity.*

The following loads are connected in parallel to a 240 V single-phase supply:

(*i*) *3 kW at unity power factor, and*
(*ii*) *5 kW at 0·5 power factor lagging.*

Determine:

(*a*) *The overall power factor of the system,*

(*b*) *the capacitance that must be connected in parallel with the loads to bring the overall power factor to unity, and*

(*c*) *the total current taken from the supply before and after this capacitor is connected.*

A16 [For the first part of the question refer to a standard textbook.]

(*a*) The total active power P, is given by

$$P = 3 + 5 = 8\ \text{kW}.$$

The total reactive power, Q, is given by

$$Q = P_5 \times \tan \phi,$$

where P_5 is 5 kW and ϕ is the phase angle which is equal to $\cos^{-1} 0\cdot 5 = 60°$.

$$\therefore \quad Q = 5 \times \tan 60° = 8\cdot 66 \text{ kvar}.$$

Therefore the total power of the system is given by

$$S = \sqrt{(P^2 + Q^2)} = \sqrt{(8^2 + 8\cdot 66^2)}, = 11\cdot 79 \text{ kVA}.$$

If ϕ_T is the overall phase angle, the power factor is given by $\cos \phi_T$.

$$\cos \phi_T = \frac{P}{S} = \frac{8}{11\cdot 79} = \underline{0\cdot 68 \text{ lagging.}}$$

(*b*) In order to bring the power factor to unity, current flowing in the capacitor, I_C, must be

$$I_C = \frac{Q}{V} = \frac{8600}{240} = 36 \text{ A}.$$

$$\therefore \quad X_C = \frac{V}{I_C} = \frac{240}{36} = 6\cdot 65\ \Omega,$$

where X_C is the capacitive reactance.

The capacitance, C, is given by

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi \times 50 \times 665}, = \underline{480\ \mu\text{F.}}$$

(*c*) The current before correction

$$= \frac{11\ 800}{240} = \underline{49\cdot 2 \text{ A.}}$$

The current after correction

$$= \frac{8000}{240} = \underline{33\cdot 3 \text{ A.}}$$

Answers contributed by I. McKenzie Smith

SCOTEC: SWITCHING SYSTEMS III 1982

Students were expected to answer all questions in section A and 4 questions in section B. The time for the examination was 3 h. There were 5 marks for each question in section A and a total of 25 marks for each question in section B.

SECTION A

Q1 List the items replaced by stored-program control (SPC) equipment in a local Strowger director exchange.

A1 In a local Strowger director exchange, SPC equipment replaces

(*a*) A-digit selectors,

(*b*) directors, and

(*c*) local registers.

Q2 Where in a director-area tandem exchange are auto-to-auto relay-sets located?

Why are regenerators associated with these relay-sets?

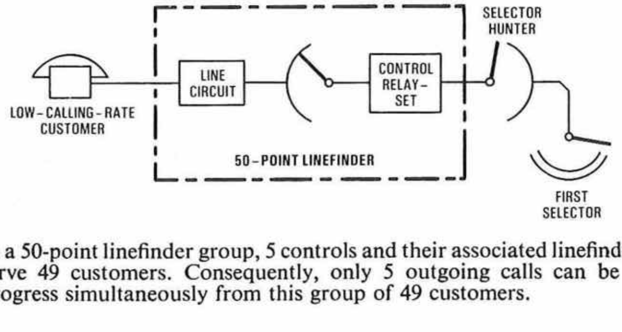
A2 The auto-to-auto relay-sets can be located either between the first and second tandem selectors, or associated with the outgoing junctions.

Because loop-disconnect pulsing is limited to lines with a maximum resistance of 2000 Ω, calls via tandem exchanges require pulse regeneration.

Q3 Show by means of a simple sketch how a low-calling-rate subscriber is connected to a first selector.

What is the maximum number of simultaneous outgoing calls from such a group?

A3



In a 50-point linefinder group, 5 controls and their associated linefinders serve 49 customers. Consequently, only 5 outgoing calls can be in progress simultaneously from this group of 49 customers.

Q4 When originating a call in a director exchange the number of digits dialled could be 3, 7 or 10, what type of calls would result?

Name the short-holding-time equipment used in EACH *case.*

A4 (*a*) *3-digit call* Code-only call. A-digit hunter, A-digit selector and director.

(*b*) *7-digit call* Call to home or adjacent director exchange. A-digit hunter, A-digit selector and director.

(*c*) *10-digit call* National number STD call. A-digit hunter, A-digit selector and local register.

Q5 State the functions of an outgoing supervisory relay-set in a TXE2 exchange.

A5 The outgoing supervisory relay-set provides

(*a*) a transmission bridge,

(*b*) supervisory tones,

(*c*) metering,

(*d*) coin-and-fee-checking repetition,

(*e*) manual hold, and

(*f*) caller control of the call.

Q6 Why are metering-over-junction (MOJ) facilities provided on STD junctions?

A6 Metering on local calls is controlled by equipment in the local exchange. Metering rates for STD and international direct-dialled calls are determined by equipment at the group switching centre (GSC). Meter pulses from the GSC are repeated back to the originating exchange as line polarity reversals, which are detected by equipment at the local exchange and cause the customer's meter to be incremented.

Q7 Explain the term 'overall grade of service' in respect to a 5-digit numbering scheme non-director exchange.

A7 In a 5-digit non-director exchange there are 4 grading stages. The overall grade of service is calculated from the total number of calls lost over all the 4 stages.

Q8 Name 2 types of queueing.

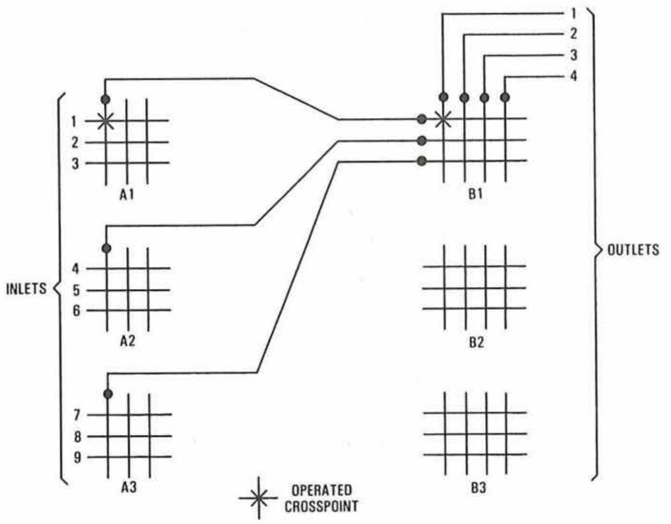
A8 (*a*) Random queueing—random selection of calls at the operator's discretion.

(*b*) Disciplined queueing—calls organised in sequential order.

Q9 What is meant by internal blocking?

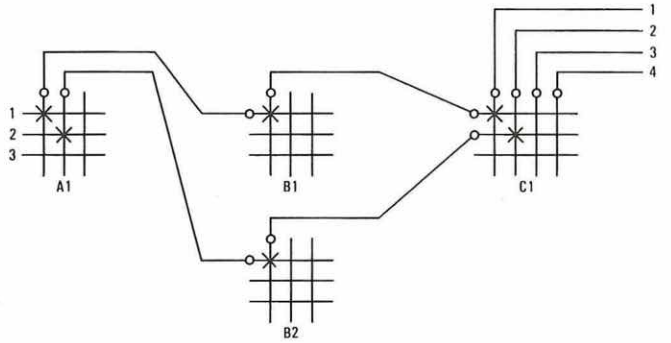
A9 Internal blocking can be demonstrated by the following example.

The sketch shows a number of interconnected switching matrices in a 2-stage switching system. If, for example, inlet 1 is switched to outlet 1, then inlets 2 and 3 cannot access outlets 2–4.



Q10 *What steps are taken to minimise internal blocking?*

A10 Internal blocking can be reduced by using intermediate switching stages. If a link cannot be made via one intermediate switch, then it may be possible to use another intermediate switch (see sketch).



SECTION B

Q11 *Using a simple block schematic diagram describe the progress of an own-exchange call in a TXE2 exchange.*

Why is 'route change' usually necessary in this type of call and when is it effected?

Q12 (*a*) *Define the term 'erlang'.*

(*b*) *A small non-director exchange of 800 lines has a busy-hour calling rate of 1·2.*

(*i*) *Calculate the number of calls originated during the busy hour.*

(*ii*) *What amount of traffic flows if the average holding time of a call is 3 min?*

A12 (*a*) The erlang is the unit of traffic intensity or traffic flow. The traffic intensity, in erlangs, on a group of circuits or switches is the average number of simultaneous calls during a period.

If T is the period, t is the average duration of a call and C is the number of calls, then the traffic intensity, A, is given by

$$A = \frac{C \times t}{T} \text{ erlangs.}$$

For planning purposes, the busiest hour of the day, known as the *busy hour*, is used for the period (that is, $T = 1$ h).

(*b*) (*i*) Number of lines = 800.

Calling rate per connection = 1·2 erlangs per connection.
Therefore, the number of calls originated in the busy hour

$$= 800 \times 1{\cdot}2 = \underline{960 \text{ calls.}}$$

(*ii*) The average call holding time = 3 min = 0·05 h.
Therefore, the traffic carried

$$= \frac{C \times t}{1} = 960 \times 0{\cdot}05 = \underline{48 \text{ erlangs.}}$$

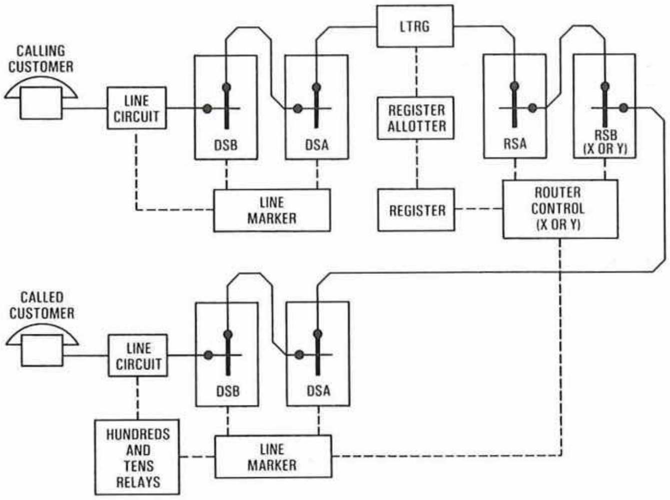
Q13 (*a*) *By means of a block schematic diagram describe the setting up of an own exchange call in a TXK1 (crossbar) local exchange. (Assume subscribers involved are on different DSBs).*

(*b*) *Why are incoming junctions from Strowger exchanges served by transmission relay groups (TRGs) connected to separate sets of registers?*

A13 (*a*) The sketch shows a block diagram of the equipment involved in setting up an own-exchange call in a TXK1 exchange.

When a customer originates such a call, a signal is passed from the line circuit to the distributor switch B (DSB). Provided one inlet of that DSB is free, the switch extends the calling signal to the line marker, where the caller's DSB outlet is identified. [*Tutorial note*: DSB inlets are connected to distributor switch A (DSA) outlets, and DSB outlets are connected to the line circuits.]

The line marker instructs the DSB to mark all free links to DSAs. Each DSA marked is instructed in turn to mark its free local transmission relay-groups (LTRGs). When a free LTRG has found a free register (via the register allotter), a signal is returned from the relevant DSA to the line marker. The line marker switches the DSB inlet through the DSA to the LTRG, and the speech and control wires are extended to the register. The LTRG returns an earth on the P-wire to operate the DSB bridge magnet, thereby switching the call through the DSB. The register returns dial tone to the caller. The DSB signals to the line marker, which releases the marked DSAs not subsequently used to establish the connection. The DSA and DSB that were used to establish the connection are now available for use by other callers.



The dialled digits are stored in the register, and the register associates with one of the router controls (say, router control X), to which it passes the called number. The router control identifies the appropriate line marker, and instructs it to mark the appropriate hundreds, tens and units leads. The hundreds and tens marking relays operate to provide access, via the line marker, to the DSB outlet, thereby permitting the line to be tested. If the line is busy or unobtainable, the router control instructs the LTRG to return an appropriate tone.

The DSB outlet to the called subscriber's line circuit and all free inlets from DSAs are marked. From these DSAs, free-link marking signals are extended back to router switches B (RSBs) X in the router control concerned with the call. The RSBs X return the marking signal to all the associated RSAs, but only the RSA connected to the LTRG concerned can receive the signal. The router control applies an earth to the P-wire via the register and LTRG to switch the marked RSA crosspoint. This allows the RSB X, DSA and DSB crosspoints to operate in succession, connecting the LTRG to the called line. The router control makes a continuity check of the allocated speech path and, if this is successful, the router control and register release. Ringing tone and ringing current are applied by the LTRG, which from then on controls the connection. If the continuity check is unsuccessful, a second attempt is made to set up a connection to the called line by using the alternative path via RSBs Y.

(*b*) Incoming TRGs are connected to separate sets of registers to afford them higher priority. This is essential since a fair proportion of the inter-digit pause may have been used at the Strowger exchange while the equipment is switched to the TXK1 junctions.

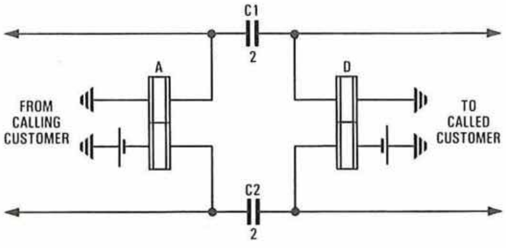
Q14 (*a*) *Sketch and describe* TWO *types of transmission bridge listing the equipment used.*

(*b*) *Discuss the advantages of each type.*

(*c*) *How is the separation of speech and signalling achieved in each type?*

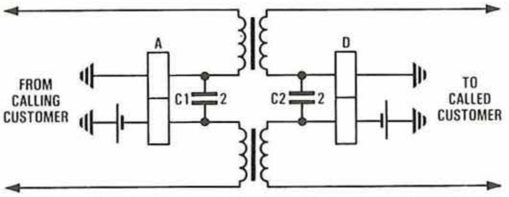
(*d*) *Explain '2-stage drop back'.*

A14 (*a*) (*i*) The circuit of a capacitor-type transmission bridge is shown in sketch (*a*). Blocking capacitors C1 and C2 isolate each side of the bridge from DC but permit speech currents to pass. Line current is fed to each circuit by 2 relay coils, which are of high impedance to prevent speech currents being shunted. Speech currents are kept away from the exchange battery, and thus prevent overhearing.



(*a*)

(*ii*) A transformer-type transmission bridge is shown in sketch (*b*). Speech coupling from opposite sides of the bridge is obtained by means of the 4 windings of the transformer. Line current is fed to the circuits on both sides of the bridge by relays A and D, which do not need to be high impedance. Capacitors C1 and C2 form DC blocks and present a low impedance to speech.



(*b*)

(*b*) The capacitor-type transmission bridge uses fewer components and takes up less space than the transformer type.

The transformer-type of bridge has the following advantages:

(*i*) It has a better loss/frequency characteristic.

(*ii*) It is not influenced by longitudinal voltage surges so that pulse distortion is reduced and, when used in a tandem connection, it has a predictable pulsing performance.

(*iii*) Low-impedance high-speed pulsing relays can be used, improving pulsing performance.

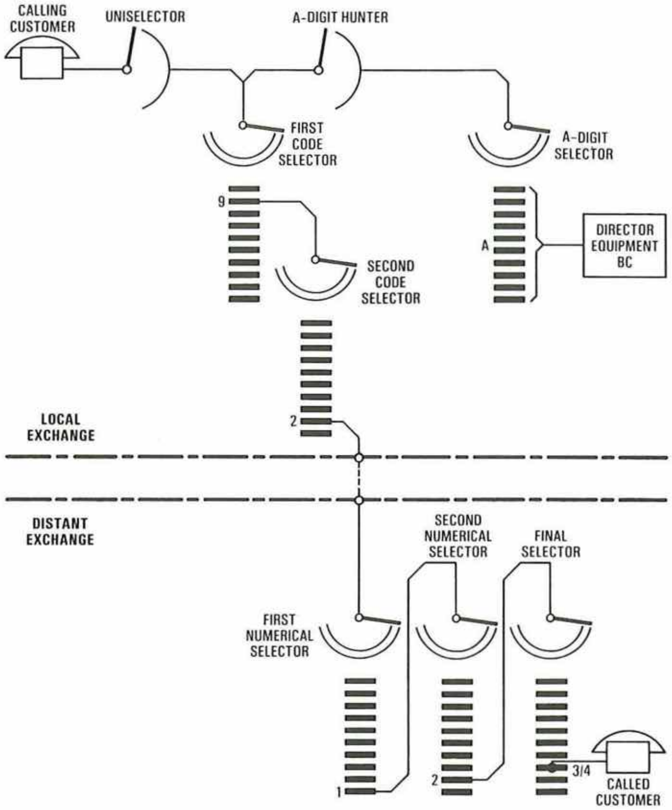
(*c*) In both cases, AC signals are permitted to pass across the bridge with minimum attenuation, whereas DC signals are confined to either side.

(*d*) To prevent oscillatory currents causing a false operation of the distant A relay during the inter-digit pause, the outgoing pulsing loop has circuitry which allows partial and then full fluxing of the supervisory relays (relays D and I), and thus prevents any instantaneous collapse of line current.

Q15 *Describe with the aid of a simple trunking diagram how a call is set up to a subscriber in an adjacent director exchange interconnected by direct junctions from a second code level.*

Provide an example of a typical director subscriber's number and routeing digits. Explain the difference between digits dialled and digits received by the code selectors.

A15 When the calling customer lifts his handset, a switching train is initiated to connect the call to an A-digit selector via the customer's uniselector, the first code selector, and the A-digit hunter (see sketch). The A-digit selector returns dial tone to the caller.



The customer dials in the A, B and C digits, which allow the director to return a translation, in this case the digits 92. These digits position the wipers of the first and second code selectors, respectively. The numerical digits from the caller are then regenerated sequentially by the director into the first, second and final selectors in the adjacent exchange. At this point the short-time holding equipment is released, leaving the customer listening to a tone from the final selector.

The caller has dialled ABC 1234, where ABC represent the all-figure number code of the desired exchange. The digits 92 are routeing digits resulting from the translation of digits BC by the director group off level A of the A-digit selector. The called customer's number 1234 gives rise to the thousands, hundreds, tens and units received, stored and regenerated by the director equipment to operate the selectors in the terminating exchange.

Q16 (*a*) *Show by means of a trunking diagram how an STD call is set up from a non-director exchange to its group switching centre* (*GSC*).

(*b*) *Show the position of the auto-to-auto relay-sets.*

(*c*) *Describe how metering is effected at the pre-determined rate.*

Answers contributed by M. C. McNeill